SCIENCE IN SPORT

MADE

PHILOSOPHY IN EARNEST.

SCIENCE IN SPORT

MADE

PHILOSOPHY IN EARNEST

BEING

AN ATTEMPT TO ILLUSTRATE SOME ELEMENTARY PRINCIPLES OF PHYSICAL KNOWLEDGE BY MEANS OF

TOYS AND PASTIMES

EDITED BY

ROBERT ROUTLEDGE, B.Sc., F.C.S.

Author of "Discoveries and Inventions of the Nineteenth Century"

THIRD EDITION

WITH ILLUSTRATIONS

LONDON

GEORGE ROUTLEDGE AND SONS, LIMITED

BROADWAY, LUDGATE HILL

MANCHESTER AND NEW YORK

1893

**Sed, veluti pueris absinthia tetra medentes
Quum dare conantur, prius oras pocula circum
Contingunt mellis dulci flavoque liquore,
Ut puerorum ætas improvida ludificetur
Labrorum tenus, interea perpotet amarum
Absinthi laticem, deceptaque non capiatur,
Sed potius tali facto recreata valescat;
Sic ego nunc, quoniam hæc ratio plerumque videtur
Tristior esse, quibus non est tractata, retroque
Vulgus abhorret ab hac, volui tibi suaviloquenti
Carmine Pierio rationem exponere nostram,
Et quasi Musæo dulci contingere melle.**

LUCRETIUS.

PREFACE.

HAD the design to which this volume owes it origin been carried out as at first conceived by the present author, his name would have appeared on the title-page in a merely subordinate position. The task he began by proposing to himself, was the preparation of an improved and modernized edition of a book which he believes has done good service in spreading a taste for science among the youth of more than one generation. The work here alluded to was written fifty years ago by Dr. J. A. Paris, and was entitled *Philosophy in Sport made Science in Earnest; being an Attempt to Illustrate the First Principles of Natural Philosophy by the Aid of Popular Toys and Sports.* On commencing the undertaking, however, it soon appeared to the writer of these lines that by no merely verbal alterations could the original volumes be brought into harmony with the existing state of science, or be made to accord with his own ideas of the best mode of carrying out the professed design of the work. He determined, therefore, to treat the subject afresh; to re-write with extensions the whole of the scientific matter, and make large additions to it; and while in part adapting (usually under changed names) the *dramatis personæ* of the story interwoven in the original with the scientific conversations, to substitute for that story a quite different, much slighter, less intricate, and perhaps more probable tale.

The writer has not hesitated to make a free use of Dr. Paris's volumes, by transferring to these pages, with more or less modification, passages or incidents which appeared suitable for his purpose. How far the present volume,

though identical in design and machinery with "Philosophy in Sport," is practically a new work, those who are curious in such matters may ascertain for themselves, by comparing the chapters of this book with those of its predecessor. For the idea of making toys and sports available in inculcating scientific truths, and for the plan by which that idea is here presented to the reader, credit is due to Dr. Paris; and it appeared to the writer that the title of the present volume—which title is but slightly altered from that of the original work—would be sufficiently significant as an acknowledgment of the obligations under which the following pages lie. It may be noted also, that the two words, *philosophy* and *science*, which enter into the antithetical title, are no longer equivalent to each other, as they were half a century ago. Philosophy is now a more comprehensive term than science, and hence the title acquires additional significance. Nor, in the body of the work, has the present author been unmindful of the title; for he has, on one or two occasions, endeavoured to bring his reader within sight of the *philosophy* of a subject, although he has never actually led him away from the Delectable Mountains of established physical truth, in order to roam in the Debatable Land of speculation.

It is no part of the design of the following pages to present a body of instruction in any of the subjects on which they treat. It is, indeed, hoped that the science is accurate, as far as it goes; and that any reader who may be tempted afterwards to take up graver treatises, will at least find that he has nothing to unlearn. But perhaps the aim of the book may be best and most briefly indicated by a familiar metaphor. It does not aspire to provide strong meat for the sustenance of those who have grown to their full mental stature; it does not even profess to supply the babes and sucklings of science with an adequate amount of their proper nutriment: it merely offers little tastes and sips of the intellectual cheer with which the rich table of science is spread. Not tit-bits—not

spiced and sugared morsels—but genuine samples of such substantial and wholesome fare as science abundantly provides for all who desire a place at her ample board. The viands are the same, though the dishes are here garnished with a leaf or two of Parnassian laurel. So that the guest who comes to our little banquet expecting nothing but sweetmeats, will probably go away disappointed. Or, changing our metaphor to that set forth in the prefixed motto, we may say at once, the honey has not been spread with so lavish a hand that any one to whom the salutary draught is utterly repugnant will find much satisfaction in licking the edges of the cup.

The author has taken considerable pains to suggest to his readers clear ideas on such subjects as *force*, *mass*, *weight*, *gravitation*, and *momentum*. On these topics great vagueness and confusion prevail in the minds of people in general, and there are not a few books of popular science which contain erroneous or misleading statements on such points. These and some other subjects on which misconceptions are rife—as, for example, the nature of sound-waves—the author has treated with more fulness than might have been expected in a book so elementary in its range. A subject of the highest importance—the very key-note of modern physics—has been introduced in Chapter XV., and the young reader who shall make the ideas there propounded his own, will not fail to find his reward. In the development of the scientific principles, some examples are presented of the entirely experimental method, as, for instance, in Chapter III.; and, in general, the inductive process is preferred. But this could not be carried on throughout without interfering with the general design of the work, and therefore a didactic and narrative treatment is necessarily adopted in dealing with some of the topics.

R. R.

CONTENTS.

CHAPTER V.

CHAPTER VI.

CHAPTER VII.

CHAPTER VIII.

CHAPTER IX.

CHAPTER X.

CHAPTER XI.

CHAPTER XII.

CHAPTER XIII.

CHAPTER XIV.

CHAPTER XV.

CHAPTER XVI.

CHAPTER XVII.

CHAPTER XVIII.

CHAPTER XIX.

CHAPTER XX.

CHAPTER XXI.

CHAPTER XXII.

APPENDIX.

SCIENCE IN SPORT.

CHAPTER I.

Fair scenes for childhood's opening bloom,
For sportive youth to stray in;
For manhood to enjoy his strength;
And age to wear away in.

THE summer recess of Mr. Pearson's school was not more anxiously anticipated by the scholars than it was by the numerous family of Seymour, who, at the commencement of the year, had parted from a beloved son and brother for the first time. As the season of relaxation approached, so did the inmates of Overton Lodge (for such was the name of Mr. Seymour's

seat) betray increasing impatience for its arrival. The three sisters, Louisa, Fanny, and Rosa, had been engaged for several days in preparing the little study which their brother Tom had usually occupied. His books were carefully arranged on their shelves; and bunches of jasmine and roses, tastefully disposed about the apartment, revealed the handiwork of the affectionate girls, whose smiles of welcome each flower seemed to reflect from its glowing petals.

At length the happy day arrived; a carriage drew up at the front gate, and Tom was once again folded in the arms of his affectionate and delighted parents. The little group surrounded their beloved brother, and welcomed his return with all the warmth and artlessness of juvenile sincerity.

"Well," said Mr. Seymour, "if the improvement of your mind corresponds with that of your looks, I shall indeed have reason to congratulate myself upon the choice of your school. But have you brought me any letter from Mr. Pearson?"

"I have," replied Tom, who presented his father a note from his master, in which he spoke in high terms of Tom's general conduct, and of the rapid progress which he had made in his studies.

"My dearest boy," exclaimed the delighted father, "I am more than repaid for the many anxious moments which I have passed on your account. I find that your conduct has given the highest satisfaction to your master, and that your good-nature, generosity, and above all your strict adherence to truth, have won you the love and esteem of your schoolfellows."

This gratifying report brought tears of joy into the eyes of Mrs. Seymour; Tom's cheek glowed with the feeling of conscious merit; and the sisters interchanged looks of mutual satisfaction. Can there be an incentive to industry and virtuous conduct so powerful as the exhilarating smiles of approbation which the schoolboy receives from an affectionate parent? Tom would not have exchanged his feelings for all the world, and he internally vowed that he would never deviate from a course that had been productive of so much happiness.

"But, come," exclaimed Mr. Seymour, "let us all retire into the library. I am sure that our dear boy will be glad of some refreshment after his journey."

We shall here leave the family circle to the undisturbed enjoyment of their domestic banquet, and employ the opportunity

to present the reader with a short sketch of the character of a person who is to perform a part in our little drama.

The Reverend Peter Goodenough, Master of Arts, Fellow of the Society of Antiquaries, and Vicar of Overton—for we must introduce him in due form—was about fifty-two years of age, twenty of which he had spent at Cambridge, as a resident Fellow of Jesus College. He had not possessed the vicarage of Overton above eight or nine years; and, although its value scarcely exceeded a hundred and eighty pounds a year, so limited were his wants and so frugal his habits, that he generally contrived to save a considerable portion of his income, in order that he might devote it to purposes of charity and benevolence; but his charity was not merely of the hand, but of the heart; he fed the hungry, nursed the sick, and cheered the unfortunate. His long collegiate residence and studious life had imparted to his mind some peculiarities, and a certain stiffness of address and quaintness of manner which at once distinguish the recluse from the man of the world; in short, as Shakespeare expresses it, "he was not hackneyed in the ways of men." His face was certainly quite the reverse of everything that could be considered good-looking, and yet when he smiled, there was an animation that redeemed the irregularity of his angular features; so benevolent was the expression of his countenance, that it was impossible not to feel that sentiment of respect and admiration which the presence of a superior person is wont to inspire. His superiority, however, was rather that of the heart than of the head; not that we would insinuate any deficiency in intellect, but that his moral excellences were so transcendent as to throw into the shade all those mental qualities which he possessed in common with the rest of the world. He was well read in the classics, and indeed was so devoted to ancient authors, that he seldom lost an opportunity of quoting some favourite poet, and these quotations were generally apposite and sometimes even witty; for he would on occasion apply a passage in a sense never dreamt of by the poet, and yet so pertinently, that it seemed really intended for the matter in hand. He delighted in a *lusus verborum* in the Latin language; but of such contradictory materials was he composed, that he regarded a pun in English with an antipathy perfectly ridiculous in its intensity. His favourite, and we might add his only pursuit beyond the circle of his profession, was the study of antiquities. He was, as we have already stated, a Fellow of the

Society of Antiquaries, and had collected a very tolerable series of ancient coins, to say nothing of other objects: for though a coin bearing the image and superscription of our reigning monarch would pass through his hands as easily as water through a sieve, he grasped with insatiable and relentless avarice any piece impressed with the head of Antonine or Otho. His collection comprised specimens of Roman lamps and pateræ, pieces of old armour, a few small antique bronze figures, and some curious mediæval musical instruments. He was also to some extent a bibliomaniac, for he greatly prided himself upon the possession of certain old folios, first editions, quartos, Elzevir classics. Then he had black-letter ballads, and rare broadsides every one of which was at least a century and a half old; and, still better, he possessed a choice collection of early prints and woodcuts, including many fine specimens of Albrecht Dürer. As might be inferred from his limited means, his collection was not formed by lavish expenditure, but was, as he himself would sometimes hint with pardonable pride, the result of industry and discernment. Mr. Goodenough's figure exceeded the middle stature, and was so extremely slender as to give him the air and appearance of a very tall man. He was usually dressed in an old-fashioned suit of black cloth; but so awkwardly did these garments conform with the contour of his person, that we might have supposed them the production of those Laputan tailors who wrought by mathematical principles, and held in sovereign contempt the illiterate fashioners who deemed it necessary to measure the forms of their customers.

But let us return to the happy party at the Lodge, whom the reader will remember we left at their repast. This having been concluded, and all those various subjects discussed and questions answered, which the schoolboy, who has ever felt the satisfaction of returning home for the holidays, will more easily conceive than we can describe, Tom inquired of his father whether his old friend, Mr. Goodenough, the vicar, was well, and in the village.

"He is quite well," replied Mr. Seymour, "and so anxious to see you, that he has paid several visits during the morning to inquire whether you had arrived. Depend upon it that you will see him here early to-morrow."

"I hope I shall," said Tom, and in that wish the whole juvenile party concurred; for the vicar, notwithstanding his oddities,

was the most affectionate creature in existence, and never was he more truly happy than when contributing to the innocent amusement of his little "playmates," as he used to call Tom and his sisters.

Tom now proposed a ramble in the grounds, and his sisters readily acceded to his wishes, for they were desirous of showing him the new flower-beds which had been planned and completed since he left home. We invite the reader to bear the happy party company, in imagination, and thus obtain a glimpse of the beauties of Overton Lodge.

Mr. Seymour's residence, we must inform him, was situated on the declivity of a hill, so that the verdant lawn which was spread before its southern front, after retaining its level for a short distance, gently sloped to the vale beneath, and was terminated by a luxuriant shrubbery, over which the eye commanded a range of fair enclosures, beautified by an irregularly undulating surface, and interspersed with rich masses of wood. A piece of ornamental water was visible, winding among the trees and bushes in the lower part of the grounds, half hidden by the large oaks and spreading beeches; while on the east the eye rested on the picturesque village of Overton, with the grey tower of its church rising above the venerable yew-trees. The uniformity of the lawn was broken by occasional clumps of flowering shrubs, so artfully selected and arranged as to afford all the varied charms of contrast. Here and there a stately elm flung its gigantic arms over the sward beneath, and cast a deep shade which afforded protection from the heat of even the noonday sun of summer to the pleased spectator of the charming landscape. The grounds occupied a considerable portion of the valley, and stretched for some distance up the western part of the hill. Here might be seen flowering shrubs of every hue: the elegant foliage of the acacia was contrasted with the dark green leaves of the chestnut, and the gnarled branches of the oak were relieved by the gracefully pendulous boughs of the birch.

Several winding paths traced their mazy way through the wood, and the avenues were everywhere pervaded by the subdued light, except where the hand of taste had, here and there, turned aside the boughs, and opened a vista to bring the village into view, or to gladden the sight by a prospect of the distant landscape. At irregular intervals the paths expanded into little

verdant glades, set in the heart of umbrageous thickets; and each of these *bosquets* was adorned with a rustic edifice, or a fountain, or a sun-dial, or with a statue of some nymph or goddess, or the bust of an ancient poet or philosopher. In these adventitious embellishments of the sylvan beauty of the spot a connoisseur might have recognized the work of the earlier part of last century, for they reflected the classicism which then reigned paramount over all matters of taste, and which dictated in the arrangement of gardens and grounds a close imitation of Italian models. Thus it happened that artificial ruins, miniature temples, and other extrinsic ornaments were often employed to decorate even localities over which nature had profusely spread her own romantic charms. Now, in the vicinity of Overton Lodge, the combinations of the scenic features were so happy that, to enhance their beauty, but few touches from the hand of the landscape gardener were really needed, and those few touches had indeed been applied with the judicious art which knows how to conceal itself.

After having descended for some way, one of the paths, losing its inclined direction, proceeded on a level, and thus announced to the stranger his arrival at the bottom of the valley. What a rich display of picturesque scenery was here suddenly presented to his view! The path terminated in a rocky glen, where large masses of rock, grouped with unexpected boldness, formed a sylvan amphitheatre, which gradually rose to a towering height, and seemed to interpose an insuperable barrier between this sequestered spot and the haunts of men. Not a sound here assailed the ear, save the rustle of the summer breeze as it swept the trembling foliage, or the murmur of a small stream, which gently fretted as it encountered the slight obstacles in its course.

We are amongst those who believe that the aspects under which external nature dawns upon the opening eye of infancy, and the scenes which are built up in childhood into the associations of home, have no slight influence upon the character and upon the happiness of after-life. To one whose early years have been spent amid fair prospects, recollections of quiet beauty will come back after the joyous freshness of youth has itself gone by; and many a pleasing mental picture will revive to solace his heart in the midst of the vulgar pursuits of the working-day world, and refresh his spirit in the din and toil of life's

struggle. It is in the spring-time of existence, when curiosity and delight are poured around, that the sensibilities to the charms of nature are first awakened; and fortunate was it for our young friends, that their lot was cast where their latent sympathies might be called forth by bright flowers, and waving woods, and flowing brooks, and rocky glens, and glorious landscapes.

Such were the scenes among which, on this summer afternoon, our affectionate party strayed with fresh delight. And now returning to the mansion as they walked across the lawn, Tom asked his papa whether he remembered the promise he had made him, on quitting home for school, of furnishing him and John with some new toys and amusements during the holidays.

"I perfectly remember," said his father, "the promise to which you allude, and I hope that you equally well recollect the conditions with which it was coupled?—when the midsummer holidays commenced, I would successively supply you with new amusements, whenever you could satisfactorily explain the principles of those you already possessed. Was not that our contract?"

"It was," exclaimed Tom, with great eagerness, "and I am sure I shall win a prize whenever you will put my skill to a trial—at which trial I hope mamma and my sisters will be present."

"Certainly," replied Mr. Seymour, "and I trust that Louisa and Fanny will not prove uninterested spectators, and even Rosa is of an age to understand some of the subjects. Little John, too, will profit by our scheme; for I shall often require for illustration certain toys which can scarcely afford any amusement to a boy of your age and acquirements, and it is but fair that they should be transferred into his hands."

"Thank you! thank you! dear papa," was simultaneously shouted by several voices, and the happy children looked forward to the morrow, with that mixed sensation of impatience and delight which always attends juvenile anticipations.

CHAPTER II.

By that kind school where no proud master reigns,
The full free converse of the friendly heart,
Improving and improved.

THE apartment in which Mrs. Seymour and her daughters usually pursued their morning avocations, opened upon the lawn already described; Mr. Seymour's library window was at the eastern side of the house, and commanded a more extensive prospect. On the turf before the windows, while his mother and elder sisters were occupied in their morning-room, Tom was running races or playing at ball with his little sister Rosa; but every now and then Tom could not help thinking of papa and his promise; and he would lead Rosa to the other side of the lawn, to steal a peep into the library, in the hope of finding that his papa was preparing to quit it. After many an anxious peep, they at length had the satisfaction of seeing him throw aside his

papers. At this signal they both set up a shout of triumph that would have astonished the female party, had they not immediately discovered its meaning by the repeated cry of—"Papa is coming! papa is coming!" Work, books, and drawings were quickly laid aside, and all were prepared to share in the anxiously expected pleasure.

"Tom," said Mr. Seymour, as he advanced towards his family, who had by this time assembled on the lawn, "I have not forgotten my engagement, and am now prepared to devote the rest of the morning to its fulfilment."

At this moment the servant advanced, and announced the arrival of Mr. Goodenough. Tom and his sisters immediately ran forward to meet him.

"My dear boy!" exclaimed the vicar, "I am truly rejoiced to see you. When did you arrive from school? How goes on Virgil?—eh, my boy? You must be delighted with the great Mantuan bard.—But, bless me, how amazingly you have grown! and how healthy you look!"

"Mr. Goodenough," said Mr. Seymour, "you are just in time to witness the commencement of a series of amusements which I have proposed for Tom's instruction during the holidays."

"Amusement and instruction," replied the vicar, "are not synonymous in my vocabulary—unless, indeed, they be applied to the glorious works of Virgil. But let me hear your scheme."

"I have long thought," said Mr. Seymour, "that all the first principles of natural philosophy might be easily taught, and beautifully illustrated, by the common toys which have been invented for the amusement of youth."

"A fig for your philosophy!" was the unceremonious and chilling reply of the vicar. "What have boys," continued he, "to do with philosophy? Let them learn their grammar, scan their hexameters, and construe Virgil."

"I differ from you entirely, my worthy friend: in my opinion, the principles of natural science cannot be too early impressed upon the mind, nor can a knowledge of them be too widely diffused; their application cannot fail to increase the happiness of all classes of the community, and must certainly advance and improve all the useful arts."

"Heresy! downright heresy!" exclaimed the reverend gentleman. "But the world has run mad, and much do I grieve to find that the seclusion of Overton Lodge has not secured its

inmates from the infection. The general diffusion of those wild theories, which nowadays are called by the name of science, would be nothing more than a scattering of the seeds of insubordination and a manuring of the weeds of infidelity. Would you assist in fabricating a battering-ram which might demolish our holy Church? Such must be the effect of your Utopian scheme; indeed, I fear that already

"'In nostros fabricata est machina muros,'

—as Virgil has it."

"Come, my good friend, I think that more than once the needless alarms of ecclesiastics at the progress of science has found vent in language almost identical with your own. I remember that when the Royal Society was first instituted, its promoters were accused of entertaining a design of 'destroying the established religion, of injuring the universities, and of upsetting ancient and solid learning.' Now, you must pardon me for frankly saying that I am obliged to regard your own language on this subject, like that I have just quoted, as declamation without argument."

"Without argument! Many are the sad instances I could adduce in proof of the evil effects of this new system of scientific education. Ah, when I was a student, science meant nothing but mathematics; but all that has been changed, and I am using the word in the sense in which I believe you mean it. I verily believe that unless this march of intellect, as it is called, is speedily checked, Overton will soon become a deserted village; for there is scarcely a tradesman who is not already distracted by some scheme of scientific improvement, that leads to the neglect of his occupation and the dissipation of the honest earnings which his more prudent father had accumulated; '*Meliora pii docuere parentes*,' as the poet has it. What think you of Sam Tickle, the watchmaker, who has suffered the parish clock to stand still for ten days, so absorbed has been his attention in attempting to illuminate a sun-dial by gas, in order that it may tell the hour during the absence of the sun?"

"What think I?" said Mr. Seymour; "why, that he is *in pursuit of a shadow*."

Has the reader ever observed the quivering back of a horse when goaded by the sting of a gad-fly? If so, he will readily conceive the effect this sally produced on the vicar, who, thus

disconcerted, was unable to pursue the topic upon which he had entered.

"Let us return," he said, "to your scheme of instructing your children in the principles of natural philosophy by means of toys and sports. I think there are two serious objections to your plan. In the first place, I opine that elaborate instruments are required for the demonstration of the principles of natural philosophy; and, if I am not quite mistaken in my view of the experimental sciences, these consist in a great part of the establishment of laws of quantitative relations. Every general principle in the sciences, which are commonly comprised in the term 'natural philosophy,' implies exact measurements and elaborate calculations. In mechanics, for example, forces, spaces, and intervals of time must be measured with great accuracy; and it is impossible to do this without refined instruments. I conclude, therefore, that you could not well elicit any principles of science from ordinary toys. But even if you could, I should protest, in the second place, against the *cruelty* of your scheme. Would you, with unrelenting tyranny, pursue the luckless little urchin from the school-room into the very playground—a sanctuary which the most rigid pedagogue has hitherto respected as inviolable? Is the buoyant spirit, so forcibly though perhaps necessarily repressed during the hours of discipline, to have no interval for its free and uncontrolled expansion? Your science, methinks, Mr. Seymour, might have taught you a wiser lesson; for you must well know that the most elastic body will lose its resilient property if it be constantly kept in a state of tension—'*nec semper arcum tendit Apollo.*'"

"I have not forgotten," replied Mr. Seymour, "that the observations needed for the discovery and establishment of the laws of nature must have an accuracy far beyond that which suffices in the affairs of common life. I am aware, too, that many important facts are altogether removed from the range of ordinary experience, and that special instruments are needed for their demonstration; while, in other cases that are met with in common life, the natural law acts under complex conditions, which disguise or obscure its operation, so that it can be studied only by means of appliances skilfully designed for this end. But as it is not my purpose to attempt the rigorous experimental study of the principles of natural philosophy, but merely to try to attract the attention of young people to them, by pointing

out the manner in which their very pastimes depend upon the operations of these principles, may not a game at marbles, for example, or the movements of the balls on the billiard-table, help us to form clear ideas upon the subject of the collision of elastic bodies, of their velocities and directions after impact, and upon reflected motion and angles of incidence and reflection? The squirt will supply a practical proof of the effect of atmospheric pressure, from which the theory of the pump may be readily understood. The various balancing toys will elucidate the nature of the centre of gravity and line of direction. The flight of the arrow will illustrate the doctrine of projectiles; the sling will show the effect of centrifugal force; and the swing will exemplify some of the laws of oscillation. Even the soap-bubble, which has amused so many generations of children, deserves, and has received, as you know, the attention of many profound philosophers. It is not my intention to enumerate all the toys which are capable of yielding philosophic instruction; for I must remind you that nowadays not a few of the common toys of children are purely scientific inventions. Thus, a simple form of Foucault's gyroscope is sold at every toy-shop for the price of an ordinary top; and for a few shillings a boy may purchase a magic lantern, or a working model of Wheatstone's single-needle telegraph."

"I will admit," cried the vicar, "that some pastimes and toys, especially such modern toys as you have alluded to, do indeed furnish means of illustrating scientific principles, and that they could be made to yield some real instruction; but I still think it would be unkind to endeavour to associate youthful recreations with any kind of task-work."

"I believe your second objection," replied Mr. Seymour, "will turn out to be in reality founded only on the meaning which has become attached to certain words, and not on the nature of the things. Play and work, amusement and instruction, toys and tasks, are commonly, and not perhaps without reason, employed as terms of contrast and opposition—the prevalent notion being that all instruction must necessarily be attended with a painful sense of mental effort, while amusement is characterized by the absence of intellectual exertion. But it may be noticed that a child is sometimes miserable in a room full of playthings, and will often break his toys, not from a love of mischief, but for the pleasure he finds in acquiring a knowledge of their internal

mechanism. In fact, any occupation of a child which agreeably affects either his understanding or his feelings we call play or sport; but when he is required, for the sake of his future welfare, to direct his attention to something which is not accompanied by the stimulus of pleasure, he soon finds the sense of mental exertion irksome, and we call such an employment a task."

"I consider," observed the vicar, "that your distinction is just."

"We may further observe," continued Mr. Seymour, "that it is not the degree of mental effort which constitutes the difference between play and work, for when do boys exert so much thought as in carrying into effect their holiday schemes? The active exercise of the attention is, therefore, felt to be irksome only when the stimulus of pleasurable excitement is absent. Now, if we can arouse a boy's interest on any subject by exciting those feelings of curiosity, wonder, and admiration which are inherent in every one, whether in youth or manhood, the acquisition of knowledge on that subject will become the source of keen enjoyment, in which all consciousness of mental effort will be lost. It appears to me that if youthful pastimes, which are already associated with agreeable feelings in the boy's mind, can be made to afford any food for the emotions I have mentioned, we should not only enhance his enjoyment of his toys and sports by making them the occasion of scientific instruction, but we should be almost certain to create in him such a taste for the pursuit of knowledge as would carry him forward in its acquisition to his life's end; and in the delightful feelings naturally attending this acquisition, we should have provided a more effectual stimulus to intellectual effort than those artificial systems of arbitrary rewards or punishments by which we coerce youth to the performance of repugnant tasks."

"Upon my word," said the vicar, "I must confess that there is much good sense in your views. I must admit that a plan which associates the acquisition of knowledge with the vivid delights of youthful feelings is far more likely to create a taste for the pursuit, than would a system of education which prescribed irksome tasks. Some teachers, unfortunately, create in the minds of their pupils so many painful associations in connection with the works of the ancient authors, that in certain cases such pupils can never afterwards derive the least pleasure from the writers they studied at school, although the works may

be among the most delightful performances of antiquity. I myself knew a very worthy man who had a profound aversion to the glorious works of Virgil himself from this very cause."

"I believe such cases are of frequent occurrence," said Mr. Seymour, "and I recollect that Byron laments his own inability, from school associations, to feel the lyric flow of Horace or to love his verses:

"'I abhorred
Too much, to conquer for the poet's sake
The drilled dull lesson, forced down word by word,
In my repugnant youth, with pleasure to record
Aught that recalls the daily drug which turned
My sickening memory.'"

"Such being the power of early associations," resumed the vicar, "it must be admitted that if you can awaken in a boy's mind those feelings of wonder and admiration of which you have been speaking, the pleasurable interest he experiences will doubtless bear him onward in the pursuit of higher scientific truths, for it has often been found that

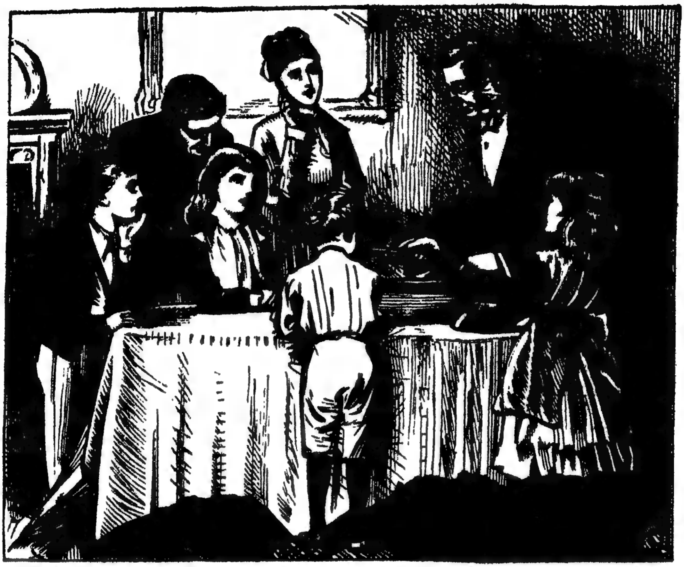
"'What the child admired,
The youth endeavoured, and the man acquired.'

I shall indeed be glad to witness the progress of your educational experiment."

"I rejoice greatly," said Mr. Seymour, "that we have at length secured your sympathy in our project: we should be glad to have the advantage of your active aid."

The vicar readily undertook to give any assistance it might be in his power to render, remarking, however, that as his own pursuits were in the direction of antiquities, and his reading had been mostly among the ancient authors, he should usually have to play the part of a silent though interested auditor and spectator of the proposed course of scientific instruction and amusement.

It was agreed that in the afternoon the children should assemble in the library, and that Mr. Seymour would then enter upon the course he had undertaken. Mr. Goodenough's parochial duties called him away in the meanwhile, but he accepted Mr. Seymour's invitation to return in the afternoon, and join the family circle at dinner.



CHAPTER III.

> And next explain we by what curious law
> The stone, termed Magnet by the Greeks, attracts
> Th' obsequious iron; magnet termed since first
> 'Mid the Magnetes, men its power descried.

TWO o'clock found the juvenile party assembled in the library, curious to know how their papa would begin the experiments and instruction which promised so much novelty.

Mr. Seymour asked little John to bring in the box of magnetic toys, which the boy's uncle had sent him a few days before.

"Oh, papa," said Louisa, "I cannot imagine how you will find anything instructive in these playthings, they are so very simple."

"I hope, my dear girl," replied Mr. Seymour, "that we shall nevertheless be able to make these toys show us some very interesting facts, by the aid of a few articles which I must ask you to obtain for me. We shall require some of the beautifully fine silk fibre which you obtained from the cocoons of your silkworms,

a few steel darning and knitting-needles, and some other things of which I have here made a list."

All the articles were quickly obtained, and John having returned with his box, was invited to display its contents. The toys were, as Louisa had said, very simple. There were gaily-painted models of fishes, which, placed in a basin of water, would dart at the rather clumsy-looking hook of magnetized steel, whenever the latter was drawn along the water near the fish's mouth. There was a model of a swan, which would swim all round the basin in pursuit of the end of the bar-magnet. After the children had amused themselves with the toys for a few minutes, Mr. Seymour said Tom or Louisa could no doubt tell John why the little models always turned their heads to the magnetized steel. John here said that Louisa had already shown him the little piece of steel at the fish's mouth, and he now knew that it was that which was attracted by the magnetic hook, for he had seen that the hook would lift up iron tacks. He thought the swan's head must also have a piece of iron or steel in it.

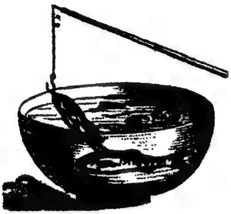


Fig. 1.

Fig. 2.

"That is quite correct," said Mr. Seymour: "it seems that you all know that the magnet attracts pieces of iron or steel. I will now perform a little experiment with the swan, the result of which may be new to you."

Mr. Seymour took the bar-magnet, and holding it exactly upright, with the centre of the bar on the same level as the bill of the swan, brought the magnet gradually nearer the model, which then happened to be stationary on the water, near to, but not touching, the edge of the basin, from which it appeared to be looking straight out, with the head almost above the rim of the vessel. When the centre of the magnet had approached to

about a quarter of an inch from the swan's bill, the children, who had attentively watched the experiment, cried out that the magnet seemed to have lost its attractive power, for the model did not change its position, although there was sufficient space between it and the edge of the basin for it to float into contact with the magnet. Mr. Seymour steadily moved the bar still nearer, always keeping it in the same position; but it was only when the bar was in contact, or nearly so, with the bill, that signs of a very feeble attraction manifested themselves. Mr. Seymour, still holding the magnet vertically, then showed that when the end of the bar was level with the swan's bill, the model would be attracted even at the distance of several inches. The children, whose interest was now thoroughly aroused, declared that only the *ends* of the magnet attracted the swan.

Tom said he had often played with magnetic toys, and it was strange he had never before seen that the middle of the magnet did not attract.

"The fact must, however," said Mr. Seymour, "have frequently presented itself in accidental combinations, but it escaped your notice because your mind was otherwise occupied. It is only when the mental attitude is one of active observation that any discovery is ever made. The facts which form the materials of scientific discoveries may, and often do, obtrude themselves upon the notice of inattentive minds without result. I think that you must have yourself performed the experiment I am about to repeat; but now it will perhaps appear to you in a new light, for it will be consciously recorded in your mind, as an instance of the truth that the magnetism of a bar-magnet is strongest at its ends."

Mr. Seymour then plunged the magnet into a quantity of iron filings (which he had provided for these experiments), and showed the children that, while the filings clustered round the ends of the bar, in the manner represented in the figure, few or none of the filings would adhere to the middle part. Mr. Seymour pointed out that the attraction, which appeared strongest near the ends, fell off by degrees towards the centre. He told them that the parts near the ends of the magnet, where the attraction seemed to be concentrated, were termed the *poles*. He now cut

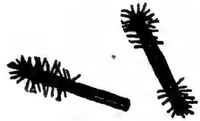


Fig. 3.

a square of paper, almost small enough to be covered with a sixpence, and bending it so that two opposite corners came into contact, he asked Louisa to tie these together, and leave some of the silk fibre attached. The end of the fibre was then fastened to the chandelier over the table, and the piece of paper formed a loop or stirrup, in which Mr. Seymour laid one of the darning-needles so that it was level, and free to turn round horizontally, by reason of the fineness of the fibre. He asked Tom to present first one and then the other pole of the bar-magnet to each end of the needle. He did so, and found that either pole of the magnet attracted each end of the needle. Mr. Seymour now replaced the steel needle with a piece of iron wire, and the same result was obtained as with the needle.

Rosa here inquired whether the magnet would attract anything but iron and steel. At her papa's invitation she sought an experimental answer to her question, by successively placing in the little stirrup an ivory knitting-needle, a vulcanite penholder, a strip of whalebone, a piece of copper wire, a narrow glass tube, a small silver spoon, and other articles. The magnet did not appear to have the least effect on any of these substances.

"It is certain," cried Louisa, "that only iron and steel are attracted by the magnet."

Mr. Seymour explained that such a conclusion could not be drawn from the experiments they had just tried, and that though they might try even a great many other substances with the same negative result, there might still be, among substances which they had not tried, some which would be affected like iron and steel. In fact, there were, he said, two other metals, namely, cobalt and nickel, which were strongly magnetic, though not to the same degree as iron. And if their magnet had been sufficiently powerful, he could show them that so far from iron and steel being the only substances affected by the magnet, in reality nearly every substance they might try would be found to be influenced by it.

"I mention this to show you that we must be careful not to extend, without just reason, the results of our experiments to cases out of the limits of our observations, unless we have good reason for knowing that these last are similar to those already examined. But let us continue our experiments. See, I take this darning-needle, and holding it flat on the table, I several times draw the end of the bar-magnet along the needle with a

gentle pressure, and always in the same direction, that is, from the eye of the needle towards its point. By this treatment the needle, as some of you know, has been converted into a magnet. See how it now holds up a tuft of iron filings from its point. But I will remove these, and now I place the magnetized needle in the little paper stirrup, and ask you to observe what happens."

"The needle is oscillating," cried Tom, "as the un-magnetized one did when the bar-magnet was near it. I suppose it will continue to move backwards and forwards for a long time, in consequence of the magnetism which has been imparted to it."

"On the contrary," replied Mr. Seymour; "it is performing these rapid oscillations because the magnetic force is striving to bring it to rest; but you will understand this better afterwards. See, now the oscillations are not so large, and presently the needle will come to a standstill."

"Oh, yes," cried Tom; "I know. It will settle so as to point exactly north."

"Well, we can now examine whether this is the case, for the needle has at length become stationary; and we can see from this window that distant church spire which, as I have told you before, appears from this spot exactly under the pole of the heavens, that is, it lies due north of Overton Lodge."

"I declare," said Tom, looking along the needle, "this magnet is by no means pointing in the direction of the church, but very much to the left of it."

"Yes," said Mr. Seymour, "it is a mistake to suppose that the magnetic needle everywhere points north and south; but its direction is sufficiently near that of north and south for us to call the pole at one end of the needle its north pole, and that at the other the south pole. You will see that when I turn the point of our needle to the south, it refuses to rest in that direction, but swings back again, and oscillates until it has settled into the same position as before. We shall, therefore, call the point of the needle its north, or north-seeking pole; and the eye the south, or south-seeking pole; and you must remember at which end each pole is situated, for I am about to magnetize a second needle exactly as before, and put it in the paper loop instead of the other. You now see that the second is settling into the same position as the first, namely, with its point northward and its eye southward. But now observe, when I bring the eye of the first needle near the point of the suspended one, how quickly the

latter turns towards it by the strong attraction between them. On the other hand, when I present the point to the point, there is powerful repulsion; and the same is the result if I try to bring the eye of the first needle near the eye of the second."

The children were much amused at seeing the apparent repugnance of the similar ends of the needles to come near each other, and every one was desirous of producing these curious effects for himself or herself. When each had in turn operated with the needles, Mr. Seymour asked Tom if he could express these effects in a very few words.

Tom replied that if it were said that magnetic poles of the same name repel, and those of different name attract each other, all the effects they had witnessed would be included.

"That is quite right," said Mr. Seymour; "and now take up the bar-magnet, and having noticed that the magnet does not attract each end of the needle indifferently, as it did before the needle was magnetized, observe how the suspended needle is affected by it at great distances. Even at the distance of a yard or more, you may cause the needle to oscillate by certain movements of the magnet."

"Yes, it is so," said Tom; "and, see, the needle is moved even when the magnet is under the table! Can the magnetic influence pass through pieces of wood without being weakened?"

"It can," replied Mr. Seymour; "and you may now try the experiment with other substances. Do you move the magnet, while I attempt to shield the needle from its influence with this large thick book. You see its interposition makes no difference, and it is the same if I place my hand or my head between the needle and the magnet."

Louisa thought it was impossible that the magnetic influence could pass through a person's head without anything being felt, and she suggested that it might go round the obstacle without passing through it, and that if the needle were placed in an air-tight box, it might perhaps then be effectually protected from the action of the magnet. Mr. Seymour said that Louisa's notion about shutting the needle up in a completely closed space was a very good one, and they could easily try it. Another needle was magnetized as before, and, by means of a fibre of silk, was suspended within an empty decanter from the cork, which at the same time served to close the vessel. The needle proved as sensitive to the magnetic influence as before; and it became

obvious to the children that the action took place *through* the solid substance of the vessel.

The juvenile party were now thoroughly interested in the subject, and many other experiments of a similar kind were performed by the children themselves. Tom communicated magnetism to the blade of his penknife, and was pleased to observe how readily it then took up steel pens, or tacks, or iron filings. He also varied the experiment of the suspended needle, by adopting a different device for allowing freedom of horizontal motion to a little magnet, which he extemporized out of a piece of steel spring, for he placed this on a slice of cork floating in the basin of water, as here shown (Fig. 4). Mr. Seymour pointed out that this was a very instructive modification of the experiment; for the fact of the floating magnet not drifting towards one or other side of the basin, clearly showed that it had no tendency to move as a whole, either northwards or southwards; or in other words, that the effect of the forces acting upon it was merely to turn it round until it pointed in a certain direction.

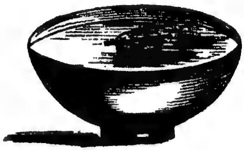


Fig. 4.

When all had sufficiently amused themselves with these effects, Mr. Seymour directed Tom to take the key out of the door, and see if he could magnetize that. Tom accordingly drew the end of the magnet along the key several times precisely as he had done with the blade of his knife, and then plunging the key into the iron filings, he found to his surprise that the key failed to attract the iron. He repeated the operation again with no better success.

"I see," he cried, "it is only steel which can be magnetized, and that the iron key, although attracted by the magnet, cannot be turned into a magnet itself."

"There," said Mr. Seymour, "you are mistaken, for iron is attracted only in consequence of itself becoming a magnet."

Tom begged his father to show them how this could be. Mr. Seymour then bringing the end of the magnet into contact with the key, lifted the latter up, and placing its lower end near the head of an iron nail, showed that the key was able to lift this up. He further varied the experiment by causing the key

to retain the nail by merely keeping the end of the magnet near to its upper extremity, as shown in the annexed cut.

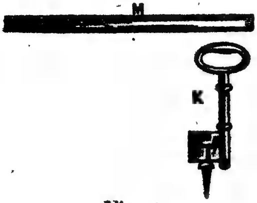


Fig. 5.

"Now, I declare," said Tom, "the key seems to be a magnet."

"It is, indeed, one," replied Mr. Seymour; "but observe that when I withdraw the magnet a very little distance, the nail drops, and this shows you that it is a magnet only so long as it is in proximity to the magnetized steel bar."

"And has the key a north pole at one end, and a south pole at the other?" inquired Tom.

"It has," answered Mr. Seymour, "and the attraction which you observe between the magnet and pieces of iron is in all cases the same kind of force which you have already noted between poles of opposite names; for I can show you that the pole next the magnet in the key is of the opposite name to the adjacent pole of the magnetized bar. But I will first exhibit an elegant method of demonstrating the action of magnetic poles."

Mr. Seymour then laid the bar-magnet flat upon the table, and having placed a large sheet of paper over it, he sprinkled

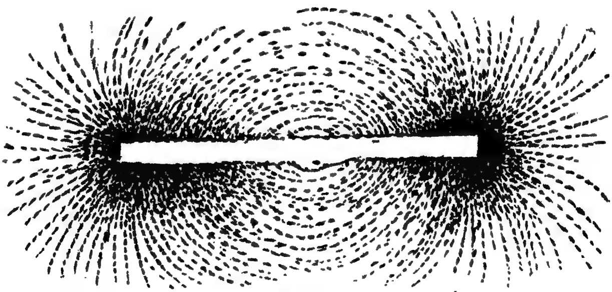


Fig. 6.

a quantity of iron filings over the paper. The filings arranged themselves into beautifully curved lines, as shown in Fig. 6, and the whole party at once perceived that these lines seemed

to spring from points near the end of the bar, where also the filings appeared to cluster most closely.

"The lines are so elegantly curved," observed Louisa, "that I am sure I could not draw them so regularly; yet each little particle of iron seems to know exactly how to place itself so as to contribute to the symmetry of the design."

"This is but one instance of what is always found in nature," said Mr. Seymour, "namely, that forces act by definite laws. The filings have only revealed to us the existence of the definite lines along which the forces of the magnet act. These lines surround the magnet in every direction, but our filings only show their form in the plane of the paper, or, to speak more accurately, the lines formed by the filings are due to the effective force which operates on particles that are free to move in the plane of the paper only. The real lines of force which surround the magnet pass through the paper at various angles. Look, for instance, at the little tufts of filings near the ends of the magnet."

"I perceive," said Tom, "that the particles of iron there are standing upright on their ends."

"Now, that shows that there the lines of force are perpendicular to the paper, or nearly so. But I will now show that the magnetism which is developed in a piece of iron has the same properties. I will take instead of the key this bar of *iron*, which is about the same size and shape as your bar-magnet, and will therefore give more regular curves; and placing its end opposite to that of the magnet at about the distance of an inch, I cover

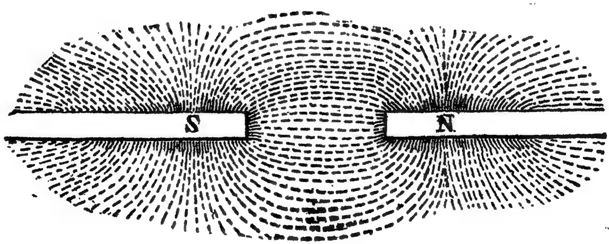


Fig. 7.

them both with the sheet of paper, and you see how the iron filings I am scattering on the paper are arranging themselves

(Fig. 7). The south pole of the magnet is under that part of the paper which I mark with my pencil by the letter "S," while the piece of iron has evidently got a pole under this part of the paper on which I now write "N," and beyond this in the iron is the corresponding south pole. Now I remove the paper with the filings, and bring over the piece of iron the needle, suspended by the fibre tied to its centre. You see how the eye of the needle, which we know is its south pole, is attracted by the end of the bar nearest the magnet; while at the other end of the iron it is the point or north pole of the needle which dips down. Now, Tom, remove the iron bar from the neighbourhood of the magnet, and see whether it retains any magnetism."

Tom did as he was directed, and declared that the piece of iron now showed no attraction for the iron filings; but he found that it, nevertheless, attracted the suspended needle, although either end of the bar now attracted either end of the needle indifferently, and he could not perceive any signs whatever of repulsion. A hint from Mr. Seymour, however, soon led Tom and the rest to perceive that the magnetized needle must have the same kind of effect on the iron as the magnetized steel bar had. They quite understood now that the neighbourhood of the magnetic pole always induced a pole of the opposite name in the nearest part of a piece of iron or steel.

"Now," said Mr. Seymour, "when I lift up the key at the end of the magnet, thus, can you show me that there is not only attraction but repulsion also in operation?"

"How can that be," cried Louisa, "when the key is lifted by the force drawing it to the magnet?"

"But you are forgetting that the part of the key farthest from the magnet is a pole of the same name as that at the adjacent end of the magnet, and is, therefore, repelled. Nay, the repulsive force is, in fact, as strong as the attractive one, but it has to operate at a greater distance, and therefore the attractive force prevails. I think also you will, on reflection, admit that there are also two forces acting from the more distant pole of the magnet, one attracting, the other repelling the key; so that what at first sight appears to be a simple attraction, we find to be in reality due to four forces, the observed result being caused only by the predominance of one set of forces over the other."

"I see now," exclaimed Tom, "the reason for something that

puzzled me just now. I was noticing how strongly the needle turned and pointed to the pole of the magnet, when the latter was presented to it at some distance; and yet I could not see that the needle showed any tendency to come bodily towards the magnet. This I can now account for, since the one pole of the needle must be repelled as strongly, or nearly so, as the other is attracted, and these equal and opposite forces would merely turn the needle round, without moving it from its place."

"Your observation is quite right," said Mr. Seymour. "When the pole of the magnet is so far from the needle that the distances of the poles of the latter differ but little, the action takes place as you have said; that is, the repulsion and the attraction are nearly equal in intensity."

"I do not understand," said Louisa, "how the difference of the distances of the poles of the needle from the magnet can be affected by the distance of the latter; for will not this difference always be about the length of the needle itself?"

"That is so," replied Mr. Seymour; "but we call the same distance small or great, according to the other distance with which we compare it. Thus an inch would be a considerable part in the height of a table, but it would be quite insignificant if we were speaking about the height of a building. If the poles of our needle are two inches apart, the *difference* of their distances from a point four inches off is much greater, compared with the distances themselves, than if the point in question were one hundred inches distant. Thus, although six inches differs from four inches by the same length as one hundred and two inches differs from one hundred inches, yet, *relatively*, in the former case it is twenty-five times greater than in the latter."

Tom suddenly announced that he thought of a method of showing separately the attractive and repulsive forces acting on the needle.

"We have only," he cried, "to break the needle across the middle into two pieces, and then, having a north pole in one and a south pole in the other, we shall see one of the pieces attracted and the other repelled."

Mr. Seymour asked Tom to try this experiment with one of the needles, and examine the result by presenting the pieces to the suspended needle. Tom accordingly snapped the needle across the middle; but he found that, while the point was a north and the eye a south pole as before, two new poles had been

produced at the fractured part, the one a south and the other a north pole, so that each moiety of the needle constituted a complete magnet with poles.

"How strange!" observed Tom; "these poles are quite as strong as the original poles of the needle: I have got two new magnets instead of one, and each has its pair of poles. I wonder what would happen if I divide each of these in the same way?"

He tried the experiment. The result was the same as before; that is to say, each piece showed a pair of poles.

"You may go on dividing the pieces," said Mr. Seymour, "as long as they are large enough to hold, but you will always find the two poles in each piece."

"But how is it," asked Louisa, "that there can now be magnetism in those parts of the needle which showed no magnetism when it was entire?"

"All these effects," replied Mr. Seymour, "will be understood at once if we imagine that the magnetized steel is built up of little particles, each of which is a complete magnet in itself, and the poles of all are turned in the same direction. You will see

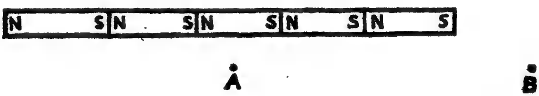


Fig. 8.

what I mean by this drawing (Fig. 8), in which a single row of such particles is represented, the north poles being indicated by *n*, and the south poles by *s*. Such a series of little magnets would produce no attractive or repulsive effect in a piece of iron at A, because whatever effect any one of the poles might have, its neighbour at the same distance would have the opposite effect. It is true, however, that there would be a north and a south pole induced in the fragment of iron. But if we place our particle of iron at B, then the attractive forces might so prevail over the repulsive forces as to move the piece of iron, for of each pair of poles, *n* and *s*, the *s* is nearer to the piece of iron. But I see, Louisa, by the perplexity depicted on your countenance, that you have not entirely understood this, so I will illustrate my meaning by an experiment. I take these iron

tacks, and applying the head of one of them to the north pole of the magnet, that part becomes a south pole, and the tack is held up; its point is for the time a powerful north pole, and you see it can in its turn induce magnetism in a second tack; to this I can add a third, a fourth, a fifth, even a sixth, and the lower extremity of this is still a pole, for it lifts up a little tuft of iron filings. Now, each tack in this chain being a magnet in itself, is attracted to its neighbour by a pole of opposite name. It is plain that the poles thus engaged, as it were, can upon pieces of iron have little action laterally."

During the performance of this experiment the vicar had entered the room, and making a sign that he did not wish to interrupt Mr. Seymour's explanation, he had taken a seat, and at once appeared much interested in the proceedings.

"That is a very ancient experiment," said Mr. Goodenough, when Mr. Seymour had concluded, "which you have been showing my young friends; for I remember it mentioned by Plato as an image by which he might explain the derivation of poetic inspiration. He speaks of the magnet attracting iron rings, and imparting to them its own virtue, so that they could sustain other rings; and thus the rings might be suspended from one another in quite a long chain, every link of which derived its sustaining power from the magnet above."

"Then," cried Louisa, "the ancients knew all about the magnet?"

"It is frequently mentioned by the ancient authors," replied Mr. Seymour; "but there is no evidence that anything was known of it in ancient times beyond the facts the vicar has referred to and a few other such circumstances, as, for instance, that the attractive power is not intercepted by the sides of bronze vessels, and so on. The ancients seem to have been quite ignorant of the polarity of the magnet, or the property which makes the little magnetized bar of steel so invaluable to the mariner."

"Oh! do tell me, papa," exclaimed Louisa, "all about the mariner's compass, and who invented it."

"Well, my dear," replied her father, "the compass is one of the inventions the origin of which is lost in the night of past ages. For although the vicar's ancient friends of Greece and Rome were unacquainted with the compass, it is generally admitted that many centuries before the commencement of the Christian era the Chinese were familiar with the use of the com-

pass for navigating the ocean, and for guiding their course across the equally trackless grassy plains of Tartary."

Mr. Seymour then explained that in the mariner's compass a magnetized bar of steel is balanced on a pivot, so that it can turn freely in the horizontal plane, and that to the magnet is attached a circular piece of cardboard, which has the cardinal points and their subdivisions marked upon it, as shown in the

Fig. 9.

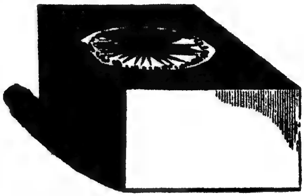


Fig. 10.

annexed figure. He also showed by a sketch, like Fig. 10, the manner in which the compass is mounted so that it may remain horizontal in spite of the motions of the vessel.

Tom and Louisa now begged that Mr. Seymour would explain why the action of the magnet on iron and steel was so powerful, while its influence on other substances was in general imperceptible.

"My dear children," replied Mr. Seymour, "it has been my desire, in this our first scientific conversation, to lead you to observe *facts* of nature for yourselves, and I have avoided any reference to speculations and suppositions; and in this course I shall, for the most part, endeavour to persevere. I may tell you that the phenomena you have witnessed to-day have never received any explanation in the sense in which I believe you use that word—that is, no one can give a satisfactory answer to your question of *why* does the magnet attract iron, or at all tell you anything which will in the least simplify the fact itself. When you are of an age to think closely for yourselves, you will perceive that much more familiar facts also refuse to yield a final answer to the philosophic '*Why?*' You are to-day, after our long conversation, as far as ever from arriving at *why* the magnet attracts

iron; but you have, I hope, learnt something of *how* it does so. And our studies to-day may have in some sort indicated to you that the province of positive science is to investigate the manner in which phenomena occur, rather than to vainly strive after an impossible knowledge of the real or final causes of things."

At the conclusion of the conversation just related, Mrs. Seymour entered the room, carrying an open letter, which she said she had just received from Laura Villiers, a young lady for whom the family at Overton Lodge entertained the highest regard. The letter announced that the writer intended in about a week to pay a long-contemplated visit to Overton Lodge.

"I am quite delighted," said Mrs. Seymour, "to hear again from Laura Villiers; for, although our acquaintance has been interrupted, her pleasing manners and amiable disposition have left a lasting impression since our last meeting her at Cheltenham."

"I shall be happy, as you well know," said Mr. Seymour, "to receive a visit from Miss Villiers; for I know that those charms of disposition and of manner to which you refer are enhanced by intellectual acquirements of a high order, and I am sure that her society will be of the greatest advantage to Louisa. I beg you will lose no time in answering her letter, and in expressing the great pleasure with which we all anticipate her proposed visit."

CHAPTER IV.

Come like shadows, so depart.

WE shall now for awhile leave the precincts of Overton Lodge, for the reader must be made acquainted with some incidents which took place in the village at the very time that our young friends were engaged in the manner just related. It happened that on that afternoon the four members of a little coterie of elderly maiden ladies, who resided at Overton, were assembled at the house of one of the set, Miss Kitty Ryland by name, for the ostensible purpose of partaking of what they were pleased to call a sociable cup of tea. We say the ostensible purpose, for there were detractors who scrupled not to assert that the real purpose of these meetings of the ancient sisterhood was the concoction of scandal, and the discussion of such incidents of family and personal histories, as ingenuity and

address, prompted by a spirit of restless curiosity, enabled them to discover. It was said that there was not a house in the parish of whose internal economy these inquisitive ladies did not know sundry small details. Mr. Seymour used to declare that although there was little difference between the four as to the pleasure they derived from these employments, yet that in the origin and circulation of the little malicious stories and bits of scandal which enlivened the local gossip, he thought he could trace the share contributed by each member of the coterie. In the manufacture of their poisoned arrows they adopted, he said, the principle of the division of labour: Miss Ryland furnished the raw material; Miss Tapps forged it into shape; Miss Sowerby sharpened the point and formed the barb; and Miss Puttle supplied it with wings.

But whatever might have been the occupations of Miss Kitty and her guests on the afternoon of which we are speaking, they were abruptly suspended when the sounds of an approaching vehicle were heard, which sounds the sharp ears of Miss Ryland at once recognized as not proceeding from any one of the hackney carriages which occasionally brought visitors to Overton from Redminster.

This extraordinary subtlety of Miss Kitty's ears is said to have been conferred upon them by those universal promoters of bodily vigour, *air and exercise*, of which they had received the combined advantage by the ingenious habit of listening to whispers through a certain pneumatic contrivance, familiarly termed a keyhole. In further proof of the fidelity and alertness of her auditory apparatus, we may just state that on passing Dr. Doseall's surgery, she never failed to distinguish, by the sound of the mortar, whether the medicines under preparation were designed for the stomachs of the rich or of the poor. The vicar even admitted the correctness of her discrimination, for he himself declared that, in the one case, the pestle beat *dactyls*, and in the other, *spondees*.

While the carriage was passing the window, the maiden companions were breathless with wonder, each catching from the countenance of her neighbour a glance, which heightened by reflection, as it were, the surprise depicted on her own.

"Overton," exclaimed Miss Sowerby, "is doubtless honoured by the arrival of some distinguished stranger; but who he is, or what may be the object of his visit, I am at a loss to divine."

"I doubt not," cried Miss Puttle, "but that the carriage has

conveyed some visitor to the vicar; for, had the Seymours expected any company, I must have heard of it yesterday."

Conjectures, however, were vain, and the party determined to resolve itself into a committee of inquiry. Betty, the maid-servant, was dispatched to the Lodge; Miss Puttle volunteered a visit to Ralph Spindle, whom Dr. Doseall employed, on the arrival of a stranger, as certain insects are said to use their "feelers," in order to discover the approach of anything that may be likely to serve them as food; Miss Margery Sowerby was of opinion that a visit to the several tradespeople in the village would be advisable; and Miss Ryland announced that she would herself proceed to Annette, the vicar's housekeeper, from whom she hoped to be able to elicit some items of interesting information. Finally, it was agreed that each should pursue such other measures as she might deem most likely to insure success, and that the party should reassemble in an hour, in order to discuss the results. This plan was accordingly carried into effect, and with what issue the reader must now be made acquainted.

By dint of active inquiry and an energetic following up of any traces of information, it was discovered that the carriage was proceeding to Ivy Cottage, a neat but unpretentious residence situated a little way out of the village. In consequence of the owner of this place having to live abroad, the residence was to be let, and it was clearly made out that the carriage had brought to Overton a gentleman who was about to occupy the cottage as tenant.

This gentleman was further discovered to be a Major Barker, and he was described as a rich but somewhat surly and eccentric old bachelor, who had spent in India nearly the whole period of his service. Such was the information which was gleaned from various sources by the four inquisitive spinsters, and on the reassembling of the conclave these particulars were duly discussed. It might be thought that as so much new material for gossip had been acquired in one afternoon, the sisterhood would have been satisfied; but, no: what they had already learned only served to pique their curiosity; and in their eagerness to know more about the new-comer and his concerns, and to be the earliest authorities on these subjects, a bold piece of strategy was agreed upon: namely, that Miss Ryland should find some excuse for seeking an interview with the gallant officer,

at the earliest possible period, and by skilful tactics endeavour to elicit, in the course of conversation, as many interesting particulars as possible.

But we must now return to Overton Lodge, where, on the following day, Mr. Seymour announced to the young people that he had that morning to show them a novelty, which, however, was hardly such a toy as could be safely left in children's own hands. It was, he said, rather a pretty form of a scientific experiment, and it would be a not inappropriate introduction to the subject he was about to discuss. In order to heighten the effect of the exhibition, he had the shutters closed, and then uncovering an object which had been hitherto concealed, the children saw a small perfectly-shaped star beaming with a strange rosy light. It was not a flame or a phosphorescent glow, but a nearly persistent gleam, which, however, sometimes seemed to be affected by a movement as if a breath were occasionally fanning it into greater brightness. The spectators were not a little puzzled by this magic light, which each declared was quite different from anything he had before seen; but when daylight was again admitted to the apartment, and they saw what the light proceeded from, they were quite astonished at the simplicity of the means by which the effect was produced. A star of metal seemed to glow with fire, but there was no apparent cause for the fire; the metal merely appeared suspended in a glass vessel.

We shall not here repeat at length the explanation of Mr. Seymour, who showed the star was in reality a very thin piece of the metal platinum cut into a stellar form, and suspended by a slender wire a little above the surface of a colourless liquid called ether. Suffice it to say that he made them understand that platinum possesses the power of so condensing the vapour of ether at its surface, that the ether there combines with the oxygen of the air, which is allowed also to enter the vessel; and that, in fact, the ether burns at the surface of the platinum without flame—the heat attending the burning being, however, sufficient to maintain the platinum at bright redness.

"I show you," said Mr. Seymour, "this curious and elegant experiment, in order that you might have an illustration of the fact that all our artificial lights are obtained by making something very hot, and that the heat is always supplied by chemical action; for, as I have to give you to-day some toys which depend for their action upon certain laws of light, I propose to take light for our subject this morning."

Mr. Seymour sent for a small looking-glass, and a glass globe in which Louisa used to keep gold-fishes, and the shutters were so arranged that only one ray of bright sunshine entered the apartment through a very small opening in the shutter. This ray of light came into the room from near the top of the window and traversed the apartment obliquely, so that it fell on the table, where it formed a bright spot of light not larger than a sixpence. This spot Mr. Seymour explained was nothing but a small image of the sun itself. He also called the children's attention to the fact that the path of the sunbeam was distinctly visible amid the obscurity of the apartment by means of the little particles of floating dust which it lighted up in its track; and he desired them to notice that the path of the ray of light was perfectly straight. The looking-glass and globe having by this time been obtained, Mr. Seymour placed the former flat upon the table, so that the sunbeam fell obliquely upon it.

"I declare," cried Louisa, on seeing the result, "that the beams seem to slant away from the glass on each side like a big **V**!"

"Yes," said Mr. Seymour; "and what I want you particularly to notice is that the inclination of the one line of the big **V** to the surface of the flat mirror is always the same as that of the other, however I may vary the inclination itself by turning the mirror."

"But if the mirror were not flat," said Louisa, "might the slope then be different?"

"The equality of the inclinations is invariable if the part of a mirror on which a ray falls be considered as flat, and in this way we might regard a curved mirror as made up of a series of small flat surfaces. The law which I am here showing you in operation is expressed scientifically by referring the inclinations to a line supposed to be drawn perpendicularly from the reflecting surface at the point where the ray meets it."

Louisa here inquired how it happened that one always seems to see through a mirror into another apartment, which appears to exist on the other side of the mirror.

"Your question reminds me," said Mr. Seymour, "of the adventures of the little girl who found such extraordinary places on the other side of the looking-glass. But the reason of the appearance you refer to is that the direction which we assign to an object depends upon the direction in which the rays from it

enter the eye, which can take no account of the previous actual course of the rays."

Tom said that he quite understood this.

"If you do," said his father, "you will be able to make me a drawing which shall explain how it is that where you are now standing, you see your sister's image in the mirror over the mantelshelf, while she sees only yours. Here are pencil and paper."

Tom acquitted himself to his father's satisfaction by produc-

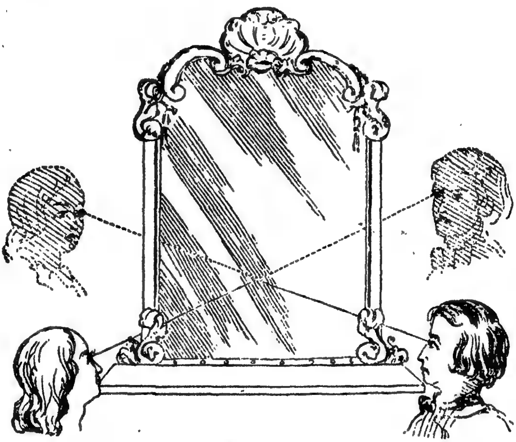


Fig. 11.

ing the annexed sketch (Fig. 11), in which he said he represented the actual path of one of the rays of light by plain lines, and the apparent path as seen by himself and his sister by dotted lines.

"I have heard," said Louisa, "of magic mirrors, into which a person looking as into an ordinary mirror, would see not her own image, but that of some one else; I do not understand how that is managed."

"I can easily explain it to you," replied Mr. Seymour, "by this sketch (Fig. 12), where I intend C to represent the partition and walls of two adjoining apartments. In each apartment is an aperture, D, which may be large enough to reflect the whole figure if filled with a mirror. But the apertures are in reality

filled with a sheet of plate-glass, surrounded by a gilt frame, so as to have the appearance of an ordinary mirror; while behind each of them, at A and B, is a real looking-glass, so large that a

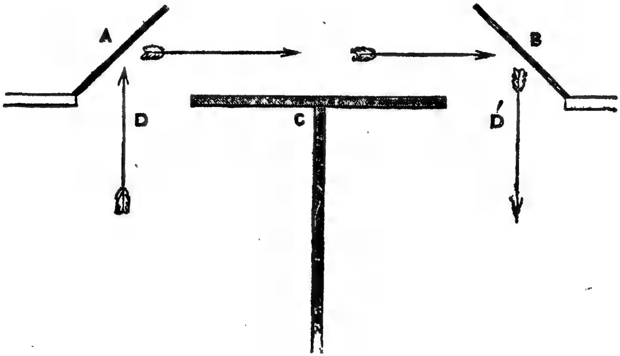


Fig. 12.

person looking into the plate-glass cannot see its edges. Each of the looking-glasses is placed at the slope I have shown, so that a person looking into either of the mirrors will not see himself, but any one who may be in front of the other glass. These arrows, for example, will indicate the direction the rays from an object in front of A will travel to reach a person in front of B, and we may imagine what must be the astonishment of a person so placed, who, having stepped up to the mirror expecting to see his own image, finds that he is apparently transformed into somebody else."

Tom suggested that it would be great fun to get a donkey to look into one mirror, while some vain fellow was trying to contemplate himself in the other.

"I believe that arrangements of this very kind," said Mr. Seymour, "have often been employed for the purpose of inducing ignorant persons to believe that they are witnessing some supernatural appearances. Suppose that the spectator, who wanted to consult some reputed magician, was solemnly conducted into an obscurely-lighted chamber hung with black, and decked out with magical and cabalistic accessories: a dark

curtain conceals the magic mirror; the magician draws it aside, and there is nothing but an ordinary looking-glass; for we may suppose that the inclined mirror, B, can turn on hinges like a door, so that it may be folded against the plate-glass, and thus heighten the subsequent deception. The curtain is again dropped, and while the pretended magician is uttering his incantations, a confederate turns back the mirror to the proper angle, and when the curtain is once more drawn aside, the objects previously arranged in front of A are seen by reflection, without the uninformed spectator receiving the least indication which would reveal the trick. Or, how startling would be the effect if the person were asked to draw aside the curtain, and after beholding his own image in the mirror, he were a second time requested to lift the curtain, and on doing so beheld a skeleton!"

The vicar asked if the concave mirror had not been pressed into the service of magic, both ancient and modern.

"It has no doubt been made use of for these purposes," replied Mr. Seymour; "and it is peculiarly adapted for producing strange effects, for it has the power of forming in the air real images of objects, which images may be of a magnitude far exceeding that of the actual object."

"It is recorded," said the vicar, "that the magicians of ancient times made the gods visible to the people amid the clouds of incense; and a certain Pontiff, who was renowned for his power in working miracles, showed a prince the image of his lost son, and it is said that the figure of the youth seemed to approach the father, but as it reached him vanished. No doubt these effects could be produced by reflection from pictures or statues."

"Perhaps one of the most striking stories of necromancy," said Mr. Seymour, "in which, from the conditions of the exhibition, we can trace the possible means by which it was produced, occurs in the Memoirs of the Florentine art-worker, Benvenuto Cellini. Here is the volume, and with your permission I will read the passage, which is amusing, and curiously illustrative of the exaggerations of impressions when a person is under the influence of terror. 'It happens,' he says, 'through a variety of odd accidents, that I made acquaintance with a Sicilian priest, who was a man of genius, and well versed in the Latin and Greek authors. Chancing one day to have some conversation with him, when the subject turned upon the art of necromancy, I, who had a great desire to know something of the matter, told

him that I had all my life felt a curiosity to be acquainted with the mysteries of the art. The priest made answer, that the man must be of a resolute and steady temper who enters upon that study. I replied, that I had fortitude and resolution enough, if I could but find an opportunity. The priest subjoined, "If you think you have the heart to venture, I will give you all the satisfaction you can desire." Thus we agreed to enter upon a plan of necromancy. The priest one evening prepared to satisfy me, and desired me to look out for a companion or two. I invited one Vincenzio Romoli, who was my intimate acquaintance, and he brought another with him. We repaired to the Coliseum; and the priest, according to the custom of necromancers, began to draw circles upon the ground, with the most impressive ceremonies imaginable. He likewise brought hither assafœtida, several precious perfumes, and fire, with some compositions also which diffused noisome vapours. As soon as he was in readiness, he made an opening to the circle; and having taken us by the hand, ordered the other necromancer, his partner, to throw the perfumes into the fire at a proper time, entrusting the care of the fire and the perfumes to the rest; and thus he began his incantations. This ceremony lasted about an hour and a half, when there appeared several legions of devils, insomuch that the amphitheatre was quite filled with them.' Cellini afterwards tells us, 'that the necromancer called by their names a multitude of demons, who were the leaders of the several legions, and questioned them by the power of the eternal, uncreated God, who lives for ever, in the Hebrew language, and likewise in Latin and Greek, and then the amphitheatre was almost in an instant filled with demons, more numerous than at the former conjuration. The necromancer requested me to stand resolutely by him, because the legions were now above a thousand more in number than he had designed; and, besides, these were the most dangerous. The boy who had accompanied us was in a terrible fright, saying that there were in that place a million of fierce men who threatened to destroy us; and that, moreover, four armed giants of enormous stature were endeavouring to break into our circle. Vincenzio Romoli quivered like an aspen-leaf. Though I was as much terrified as any, I did my utmost to conceal the terror I felt, so that I greatly contributed to inspire the rest with resolution. But the truth is, I inwardly gave myself over as a dead man. The boy placed his head between his

knees, and said, "In this posture will I die, for we shall all surely perish." In this condition,' concludes Benvenuto, 'we stayed till the bell rang for morning prayers.'

"Now," continued Mr. Seymour, "I will present you with a toy which depends entirely upon the laws of reflection for its pleasing effects. It is called the kaleidoscope, and consists of nothing but a pair of plane mirrors placed at a certain angle, so as to produce by reflection beautifully symmetrical figures. But I need not explain the construction of an instrument which I think you are familiar with, as I have seen cheap forms of the toy in Tom's hands before; and now I think of it, I remember not long ago giving Tom instructions how to make a kaleidoscope for himself."

"It was during my last holidays," said Tom; "and I had not

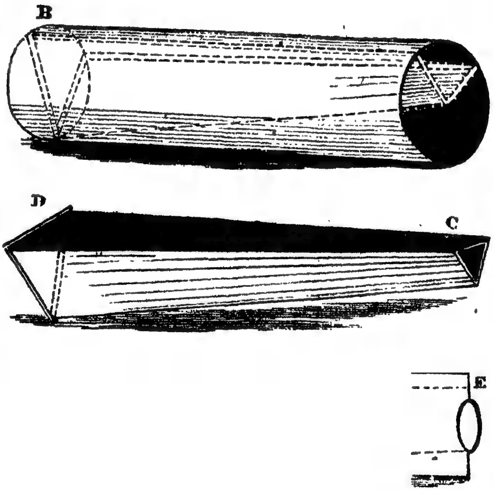


Fig. 13.

been able to get pieces of coloured glass to form the objects. Here I have in my pocket-book the sketch you gave of the arrangement of the pieces of glass painted black on the outside."

Tom produced the drawing which is shown in Fig. 13, where

A B represents the pasteboard tube, the position of the two mirrors being shown by the dotted lines, A being the end of the tube where the eye was to be placed, and B the object end. C D shows the arrangement of the mirrors in the tube, the dark shaded part representing a piece of black velvet, the whole being arranged so that the two pieces of glass and the velvet formed an exact equilateral triangle. E F shows the position of the glasses in the tube, E indicating the opening in the end at which the eye is placed, and F the box, with ground-glass cover, which receives the objects. The kaleidoscope which Mr. Seymour now placed on the table was a large and well-made instrument, mounted on a stand. The children were much delighted with it, and would have spent the morning in looking at the endless variety of beautiful figures it presented, had not Mr. Seymour requested that further examination of it should be postponed, in order that he might proceed in his explanation of the laws of light.

Tom was now directed to fill the globe about half full of water, and the shutters having been again closed, Mr. Seymour proceeded to demonstrate the fact of the refraction of light, by simply placing the globe so that the beam of light fell upon it in the manner shown in Fig. 14. He pointed out that the beam was suddenly bent where it entered the water, and instead of pursuing its straight path to A, it was in part more bent downwards, so that the round light spot appeared at B instead, and in part reflected upwards to the ceiling. In order to render the course of the ray visible in the water Mr. Seymour, put in a few drops of a tincture which communicated a very slight cloudiness to the liquid, while the track of the rays in the air was made distinctly visible by the smoke of a smouldering piece of brown paper.

Fig. 14.

"This shows you," said Mr. Seymour, "that a ray of light, in passing obliquely from one medium, such as air, into another such as water, is *refracted*, or bent aside; so that, while it pursues a straight path in each medium, there is a sudden change in direction at the common surface; but, at the same time, a certain proportion of the light is also *reflected* according to the same laws as we have observed in the case of the plane mirror."

The experiment with the beam of light was now varied in the manner shown in the annexed figure (Fig. 15), where A B is the mirror, placed on the table; and E F G H the path of the ray of light, which, this time entering the water perpendicularly at K, was not refracted, but proceeded in a straight line to G, where it did not emerge from the water into the air, but was totally reflected and bent down again to the table at H. Mr. Seymour explained that when a ray of light travelling in water meets the surface of the water at any angle, D G F, not exceeding $42\frac{1}{2}^\circ$, the ray is totally reflected as from a perfect mirror.

Fig. 15.

Louisa said she remembered seeing a perfect reflection of the objects from the surface of the water in the tank of a public aquarium, so that she had at first supposed that a mirror had been purposely placed there.

"You may at any time observe this reflection within the water by simply placing a tea-spoon in a glass of water, and looking upwards at the surface of the water. But perhaps I can recall to your mind an interesting illustration of internal reflection in water. Do you remember, when we were in London, I took you to see an exhibition called the 'Illuminated Cascade'?"

"Yes, and you promised that you would some day explain to us how that effect was produced; and now I think you said at the time that it was due to internal reflection, which we could not then understand."

"You are right; but I believe that by help of a sketch or two I can now make the whole matter clear to you. In the exhibition you saw three brilliant coloured jets of water fall from a height into a basin below; but as your brothers and sisters did not witness the exhibition, I must show them a cut which will convey some notion of the appearance of the illuminated cascade."

Here Mr. Seymour took down a book, and showed Tom and the rest the cut which is copied in Fig. 16.

"The bright light," said Mr. Seymour, "you see at the top is from what is termed an 'electric lamp,' which is an arrangement for obtaining an extremely intense light; but I will sketch also

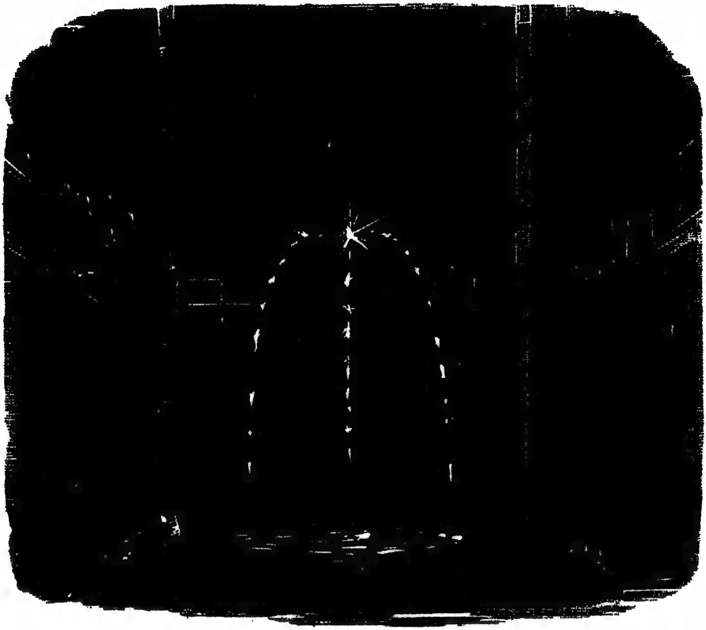


Fig. 16.

the arrangement of the light and lantern, as if one were looking down upon them from the roof of the building."

The sketch is shown in Fig. 17, where A is the electric light, and the thick dark lines are the sides of the lantern enclosing it —in three sides of which the lenses, B C D, were fitted. The circles, E F G, represent upright cylinders, each of which was fitted with a plain glass window in the side next the lens, and directly opposite was an orifice, Z, from which the water flowed. The dotted lines in the figure are to show the mode in which the lenses condensed the light, and sent it into the emerging jet of water. Mr. Seymour showed another sketch of the same arrangement, which is also copied in Fig. 17. In this, which is a section or the appearance the lantern and one of the cylinders would present if cut through the centre, I I represents the

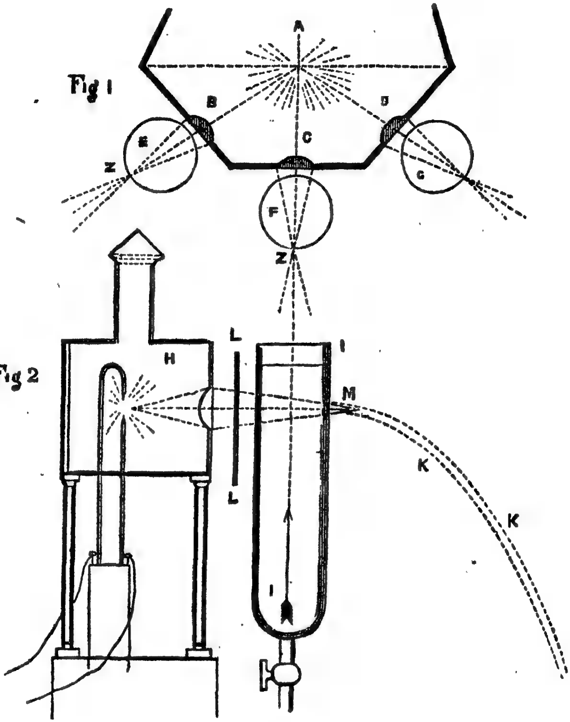


Fig. 17.

cylinder of water, which is filled from below as fast as the water issues from the orifice at M, forming the stream of illuminated water, K K; and L L shows the position of a plate of stained glass, which could be changed at pleasure so as to produce any colour.

"The light which entered the end, if I might so call it, of the descending jet of water, was reflected from side to side of the column in a way which you will now quite understand from this diagram (Fig. 18), where I have traced two rays in their repeated reflections from side to side. The rays thus reflected from side to side of the liquid would not reach the spectator at all, if the

jet continued uniform and unbroken; but the resistance of the air causes its surface to be more or less broken up by drops of water detaching themselves from the general mass; and from the irregularities thus occasioned the internal light breaks out, illuminating the drops of water as they fall, and tinging them with the various colours which may be introduced by means of the pieces of stained glass. Thus it happens that at one moment the curved column of falling water appears like a shower of diamonds; at another like jets of liquid rubies or amethysts."

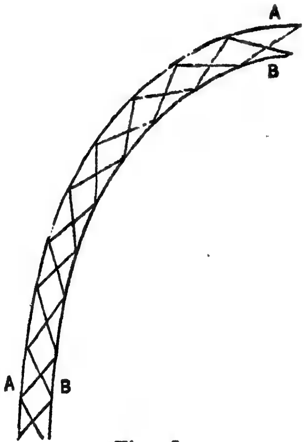


Fig. 18.

"I now understand," said Louisa, "why the water alone appeared illuminated in the cascade—a circumstance which has puzzled me very much until now."

"I have since then seen the same experiment carried out in another way, which, perhaps, was even more beautiful and impressive from the greater volume of water. The water rose up in one lofty column from the level of the floor, and fell back in a thousand streams of blazing drops into the basin beneath, producing indescribably lovely effects as it was made to glow with the various colours, the last always appearing more beautiful than all the preceding. In this exhibition, which was appropriately enough termed the 'Fairy Fountain,' the effect was produced in the same manner as in the illuminated cascade, only the light was sent up into the centre of the column of ascending water by apparatus placed below the floor of the room."

Louisa wished to know whether refraction and reflection occurred only when the rays of light met with the surfaces of liquids and solids.

"The same phenomena," replied Mr. Seymour, "may be presented at the common junction of any two media, whether solid, liquid, or gaseous. For example, if we pour on the surface of water in a glass a layer of turpentine, we shall find that, although

both liquids are perfectly transparent, the common surface reflects rays meeting it within certain angles more perfectly than the most highly burnished plate of silver. Nay, more: different strata of even the same liquid or gas, in different states of expansion from differences of temperature, will act in a precisely similar manner. Have you not often observed, when looking across the sands at the sea-shore on a very hot day, an apparent flickering or dancing movement of the distant objects?"

"Oh, yes! when people say they see the heat rising from the sand."

"An expression which is singularly inaccurate, for heat is no more visible than gravitation or magnetism. It is, however, true that the appearance we are speaking of is an effect of the heating of the sand by the sun's rays; for the heated sand communicates some of its heat to the air in contact with it, and in consequence this air becomes expanded, and being then lighter, bulk for bulk, than the surrounding air, it rises up among it. Now, the rays of light which pass through several portions of air of unequal densities are refracted with irregularities which change with the movements of the ascending currents. But more striking than these appearances are certain phantasmal effects which are occasionally, though rarely, seen in the atmosphere. Some of you have, perhaps, read about the 'mirage,' which is frequently seen in the sandy deserts of the East, where it sometimes cheats the thirsty traveller into the belief that he is approaching an expanse of water. I will, however, read you a short passage from the account which a traveller has given of the mirage as he saw it in Egypt: 'We procured asses for our party, and setting out for Rosetta, began to recross the desert, which appeared like an ocean of sand, but flatter and firmer as to its surface than before. The Arabs, uttering their harsh guttural language, ran chattering by the side of our asses, until some of them, calling out "*Raschid!*" we perceived its domes and turrets apparently upon the opposite side of an immense lake or sea, that covered all the intervening space between us and the city. Not having in my own mind at the time any doubt as to the certainty of its being water, and seeing the tall minarets and buildings of Rosetta, with all its groves of dates and sycamores, as perfectly reflected by it as by a mirror, insomuch that even the minutest detail of the architecture and of the trees might have been thence delineated, I applied to the Arabs to be informed in what manner we were

to pass the water. Our interpreter, although a Greek, and therefore likely to have been informed of such a phenomenon, was as fully convinced as any of us that we were drawing near to the water's edge, and became indignant when the Arabs maintained that within an hour we should reach Rosetta by crossing the sands in the direct line we then pursued, and that there was no water. "What!" said he, giving way to his impatience, "do you suppose me an idiot, to be persuaded contrary to the evidence of my senses?" The Arabs, smiling, soon pacified him, and completely astonished the whole party by desiring us to look back at the desert we had already passed, where we beheld a precisely similar appearance: it was, in fact, the MIRAGE! a prodigy to which we were then strangers, although it afterwards became more familiar. Yet, upon no future occasion did we ever behold this extraordinary illusion so marvellously displayed. The view of it enabled us to imagine the horrible disappointment to which travellers must be liable, who, in traversing the interminable desert, destitute of water and perishing with thirst, have sometimes this deceitful prospect before their eyes.'"

"How very curious it must be," remarked Louisa. "I suppose such sights are never seen in our own country?"

"There are," said Mr. Seymour, "many accounts of similar phenomena which have been seen in these islands, and have been recorded by competent observers. For example, Dr. Vince relates that he saw, at Ramsgate, the inverted image in the air of a ship whose topmasts only were perceptible above the sea horizon, while over the inverted image another erect image was also visible. I will sketch you what I suppose the appearance must have been when these phantom ships were viewed through the telescope (Fig. 19); for Dr. Vince was able, by that instrument, to discern all the details of the vessel in these airy images."

Little John said that his papa had drawn the real ship as if all but the upper sails had sunk beneath the waves. Mr. Seymour then explained to the little fellow that he intended the ship to be placed on the other side of the hill, as it were, which the sea formed, in consequence of its rounded surface; but that he had perhaps exaggerated a little.

"Dr. Vince," he continued, "states that the pennant at the masthead of the inverted image appeared nearly to be touching that of the real ship, seen peeping above the horizon, and that between the inverted and erect images was also a spectral sea. As

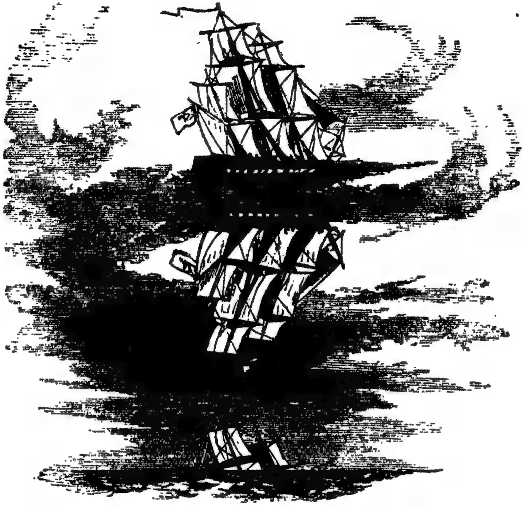


Fig. 19.

the approaching ship seemed to rise from the other side of the watery ridge, the upper image gradually disappeared; and while this was going on, the lower and inverted image as gradually descended, but the mastheads of the spectral ship never appeared exactly to touch those of the real vessel. When the latter came entirely into view, it was perceived that the aërial images had been perfect representations of it."

Tom said these spectral ships reminded him of some incidents in a story he had read, called "The Phantom Ship."

"The superstitions about phantom ships," said Mr. Seymour, "have in all probability arisen from such appearances as Dr. Vince described; and it somewhat confirms this to find that these strange craft are said to sail in the eye of the wind, or to plough through the sea when there is not a breath of air to ruffle its surface. Perhaps, also, the legend about the beacon-keeper of the Isle of France, whose magic power enabled him to see in the air vessels coming to the island long before they appeared on the horizon, had a similar origin."

Tom inquired if these aërial appearances could be represented by any experiments.

Mr. Seymour then stated that different explanations of these phenomena had been advanced, but that it was difficult to reproduce the conditions even so far as these were known. A pretty imitation of the mirage could be made by arranging layers of three different liquids in a glass vessel, with flat and perfectly even sides. The densest liquid must, of course, be at the bottom, and the lightest at the top; but it is essential that the intermediate liquid have a higher refractive power than either of the others, and this condition renders requisite some skill in the selection of liquid. Water holding in solution as much alum as it will dissolve, may form the lowest liquid, and pure water the highest, while the intermediate liquor may be colourless whisky, having so much white sugar dissolved in it as will make its density between that of water and saturated solution of alum. When the liquids are carefully floated on each other, three distinct images of objects are obtained, and the middle one is inverted. It is said that a mirage may *sometimes* be formed artificially, by heating the bottom of a sheet-iron box, with the ends removed. The spectator looks through the box, and more commonly sees nothing but a flickering of the object beyond. Sometimes, however, from some causes not understood, or under conditions unknown, which cannot therefore be reproduced at will, one stratum of air of one density will tranquilly float upon another of a different density, and then the observer sees the images of objects reflected as if in a mirror. The mirage and similar appearances are probably more often due to refraction rather than to reflection, although the latter may, in some cases, aid in producing the effect.

Louisa said she had read of a huge spectral human figure which was sometimes seen on the mountains in some part of Germany, and she would be glad if her papa would explain how this appearance was produced.

"You doubtless allude to the Spectre of Brocken. The Brocken is the loftiest summit of the Hartz Mountains, a picturesque range situated in Hanover. This summit is 3,300 feet above the level of the sea, and it commands a prospect of vast extent. The Hartz Mountains are wild and romantic, full of caverns and clefts, rivulets and waterfalls, and notable also for a festival, which was anciently celebrated here on Midsummer

Night, in honour of St. Walpurgis, a female saint who first introduced Christianity to the inhabitants. A legend had long prevailed that the summit of the Brocken was haunted by a demon, a legend to which the spectre must have given rise; for when the clouds collect in the neighbouring heights, it happens, from some cause or other which is not clearly known, that at sunrise, when the beams fall horizontally, a distinct and magnified shadow of whatever may be on the summit of the mountain is sometimes cast upon the clouds. One of the best accounts of this strange spectacle is given by a well-known French *savant*, the Abbé Hauy, who visited the Brocken in 1797, and whose statement I will read to you. He says: 'After having been here for the thirtieth time, I was at length so fortunate as to have the pleasure of seeing the spectre. The sun rose about four o'clock, and the atmosphere being quite serene towards the east, his rays could pass without any obstruction over the Heinrichshohe. In the south-west, however, towards Achtermanshohe, a brisk west wind carried before it thin transparent vapours, which were not yet condensed into thick heavy clouds. About a quarter-past four I went towards the inn, and looked round to see whether the atmosphere would permit me to have a free prospect to the south-west, when I observed at a very great distance, towards Achtermanshohe, a human figure of a monstrous size. A violent gust of wind having almost carried away my hat, I clapped my hand to it by moving my arms towards my head, and the colossal figure did the same. The pleasure which I felt on this discovery can hardly be described, for I had already walked many a weary step in the hopes of seeing this shadowy image without being able to gratify my curiosity. I immediately made another movement by bending my body, and the colossal figure before me repeated it. I was desirous of doing the same thing once more, but my colossus had vanished. I remained in the same position, waiting to see whether it would return, and in a few minutes it again made its appearance on the Achtermanshohe. I paid my respects to it a second time, and it did the same to me. I then called the landlord of the Brocken inn, and having both taken the same position which I had taken alone, we looked towards the Achtermanshohe, but saw nothing. We had not, however, stood long, when two such colossal figures were formed over the above eminence, which repeated our compliments by bending their bodies as we did, after which they vanished. We retained

our position, kept our eyes fixed on the same spot, and in a little time the two figures again stood before us, and were joined by a third (most likely by the double reflection of one of the spectators). Every movement that we made by bending our bodies these figures imitated, but with this difference, that the phenomenon was sometimes weak and faint, sometimes strong and well defined.'"

After having read this extract, Mr. Seymour made a rough

Fig. 20.

sketch of the phenomenon, similar to Fig. 20, in order that the more juvenile members of the family might have a livelier idea of the subject; but he told them that his sketch was by no means intended as a representation of the actual appearance of the spectres.

"It is obvious," he continued, "that these spectral images are nothing but magnified shadows; but it is not very easy to account for their dimensions. The shadows cast by the sun in ordinary circumstances diminish behind the object, and their edges become ill defined even at a little distance. But when we use a source of light which is itself smaller than the object, the shadows are larger than the objects; and therefore we might suppose that the rays of the sun are in some way refracted, so that they fall upon the summit of the Brocken, as if divergent from a comparatively small space."

Louisa said she did not quite understand how divergent rays

cause the shadows to enlarge. Mr. Seymour said that she might very easily understand the matter from a diagram. He accordingly drew the subjoined sketch (Fig. 21), where A represents a

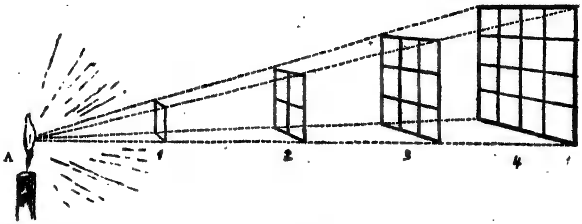


Fig. 21.

light, and 1 represents a square opaque screen at 1 ft. distance. He pointed out that the shadow would cover a board at 2 ft. distance of just four times the size, at 3 ft. one of nine times the size, and so on, supposing always that the light emanates from a very small source.

"This figure," he went on to say, "will also serve to explain to you another fact with regard to light, which will become obvious to you by simple inspection of the figure. It is that the amount of light which falls upon a surface of a given size is less in proportion as the square of the distance from the luminous source is greater. Thus, suppose that 1 represents a square opening through which the light passes; it is plain that at 2 the same light is spread out over just four times the area; consequently each of the squares equal to 1, into which it is divided, receives only one-fourth of the light that falls upon 1. Similarly each space in 3 has only one-ninth, and each of those in 4 only one-sixteenth of the light that 1 would receive."

Here it was necessary to break off the morning's discourse, for the hour of luncheon had arrived. Mr. Seymour said that he had a few more words to say to them about images, for he wished to explain how a convex lens could form an image. But as Tom and Louisa already knew how images may be formed without any lens at all, he would ask them to explain that matter to Rosa and the rest, and he himself would afterwards try to make them understand how a lens could form images; and he believed that they would be interested in this part of the subject,

for he had provided another present in the shape of a magic lantern, which he was sure would supply them with much amusement, especially during the long winter evenings.

Very soon afterwards Tom was busy showing Rosa the formation of images by means of small apertures—an experiment which Mr. Seymour had made familiar to Tom some time before. He obtained an empty cigar-box, and bored a small hole in the middle of one end, and another larger hole in the lid; then inside of the box, at the end opposite to the small hole, he pasted a piece of white paper. He now procured a small rose-plant in full flower, which happened to be growing in a flower-pot in the greenhouse. This he placed in front of the small opening in the cigar-box, so as to receive ample light, and then asked Rosa to look through the hole in the lid.

"I declare there is a little picture ot the rose-tree in the end of the box, but it is very blurred and indistinct. I can see the red patches of the flowers, and the green parts, which are the leaves. But I do believe the picture is upside down, for there is a patch of red at the bottom."

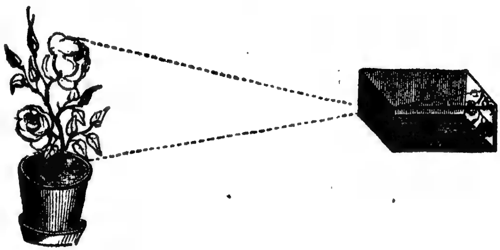


Fig. 22.

Tom now drew a diagram like Fig. 22, in order to explain to Rosa how an image is formed. The dotted lines, he said, show only two of the countless rays of light which every point in the rose sent off; but of all the rays from, say, the highest point of the flower, only one, or what might be considered one, fell upon the small opening, and passing through, continued its journey in the same straight line, until it reached the paper at the end of the box, where it showed itself by its red colour. The other dotted line, representing a ray from a point at the lower part of

the flower, passed through the opening in a similar manner, and therefore met the paper at the upper part, while the several rays from each point of the object passed through the opening in the same way.

Rosa said she now perfectly understood how it was that the image was upside down, but she wished to know why the picture was so faint.

"The reason is that so few of the rays of each point of the object can pass through the small hole."

"Then, why don't you make it larger, so that more rays can get through?"

Tom told his sister that making the hole larger would certainly permit more rays to enter, but it would also permit the rays from different parts of the object to reach the same part of the paper. In order to convince her that this would be the case, he enlarged the opening to a diameter of about a quarter of an inch. When Rosa once more looked through the hole in the lid of the box, she admitted that the little picture was no longer visible.

In the afternoon of the same day Mr. Seymour undertook the explanation of the formation of images by means of convex lenses. He reminded them of the facts that they had that morning seen, namely, that rays of light, in passing obliquely from air into such media as water and glass, or *vice versâ*, are bent out of their rectilinear path into another at a greater or less angle with their previous direction.

"The curved surfaces of this lens," said he, showing them a large reading-glass, "are such, that the rays emerging from any point and falling upon the glass are so bent from their original directions, that if the point from which the rays diverge be not too near the glass, all the rays that fall upon the lens meet together again at a point on the other side. The rays do not stop at this point, but continue their course beyond it; so that it would be correct to say that all such of the rays originally leaving the luminous point as fall upon the glass are caused by the refractions they undergo to converge towards and pass through a single point in the air on the other side of the lens. I have had this model made in order to give you a clear idea of the effect of a lens on the rays of light which leave the various points of an object placed before it."

Our readers will have no difficulty in understanding the nature

of the explanation Mr. Seymour was able to give with the help of his model which is shown in Fig. 23. It consisted simply of a thin upright wooden disc, A B, having a number of holes bored through it, through each of which a thread was passed, while the centre of the disc at C was traversed by a straight piece of thick iron wire, which could be moved about so as to form any angle within reasonable limits with the plane of the disc. This

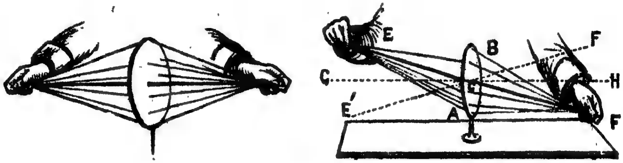


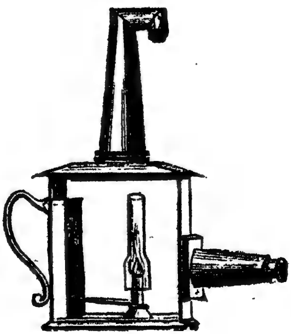
Fig. 23.

thin iron rod, E F, therefore, always passed in a straight line through the centre, C, of the disc; and Mr. Seymour stated that it was intended to represent the ray of light which passes through the very centre of the lens, and which retains its direction whatever angle it may form with the axis, G H, of the lens. The threads were intended also to represent rays of light, and by gathering these up in each hand, so that they all met at the points, E and F, on the central rod, he was able to show the course which rays from a point, E, above the axis, G H, for example, pursue; so that after refraction they again pass through another point, F, which is necessarily situated below the axis.

In this way Mr. Seymour made it clear to the children that if E be the top of a candle-flame, the focus, or point where the rays meet after refraction, must be below the axis; while, if E′ be a point at the bottom of the flame, the focus of rays from that point would be above F, namely, at F′. Having in this way shown the children how it happens that the images formed by a convex lens are inverted, Mr. Seymour proceeded to explain that the distance from the lens of the focus of rays from a given point had a certain definite relation to the distance of the point from the glass; so that if the two distances were once measured for any particular lens, the distance of the focus for any other point could be easily calculated from the distance between that point and the glass. But if the point which emits the rays

be placed at a certain distance from the lens, the rays are so refracted by the glass that they emerge from it—not converging like the threads at F, Fig. 23, but parallel to each other; while, if the point be placed still nearer to the lens, the rays, by passing through it, are made to diverge, that is, they spread out as if they issued from a point on the same side of the glass as the actual point, but farther back.

Mr. Seymour now produced the magic lantern, and when the shutters had been closed to exclude the daylight, the lantern was put into operation, to project some beautiful photographic views on a screen, to the great delight of the juveniles; and Tom and Louisa declared that they enjoyed the exhibition all the more since they now understood something of the manner in which the images were formed. Mr. Seymour took occasion to remark that the camera obscura which they saw photographers use, formed images in precisely the same manner as the magic lantern. In fact, the magnified view on the wall would, if itself luminous, send through the lens of the magic lantern rays that would form, on a slide placed in the lantern, the exact counterpart of the photographic transparency.



CHAPTER V.

Mine eyes are made the fools o' the other senses.

ON the following morning our party again assembled in the library at the appointed hour. Mr. Seymour announced that he was about to show some amusing toys depending upon certain impressions made upon the organs of vision. He then produced a small box, but before opening it, he stated that the toy he was about to exhibit was called the *Thaumatrope.*

"The name is from the Greek," exclaimed the vicar; but as his eye caught the label on the outside of the box, he added, in a lower voice, "*Timeo Danaos et dona ferentes.*"

"What is the meaning of the word?" asked Louisa.

Mr. Goodenough explained to her that it was compounded of the Greek words θαυμα and τρεπω—the former signifying *wonder*, and the latter *to turn.*

"Exactly," continued Mr. Seymour: "the box contains a

wonder-turner—a toy which performs wonders by turning round. But let me read the inscription on the cover, which, like the sign over an inn-door, is intended to make known that good entertainment is provided within." He then read the following:

"THE THAUMATROPE,
BEING
ROUNDS OF AMUSEMENT,
OR A METHOD OF
PLEASING AND SURPRISING
BY TURNS."

"It may be very clever," said the vicar; "but I do not understand it."

"But you shortly will. Pray look at one of these cards," replied Mr. Seymour, handing the vicar a little disc of pasteboard out of the box. To two opposite points on the edge of the circle of cardboard, strings were attached by which the card could be twirled round. To do this it was merely necessary to hold one of the strings in each hand, between the finger and thumb, and give it a twisting movement. Here is a sketch of the card the vicar was examining (Fig. 24), and it shows that on one side of the card was figured a bird, and on the other a cage.

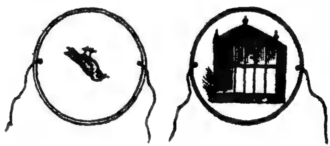


Fig. 24.

"Here is in the box," continued Mr. Seymour, "a printed paper containing the inventor's own explanation. I will read it: 'The action of this toy depends upon the fact that an impression received on the retina of the eye lasts for a short space of time after the object which has produced it has been withdrawn. During the rapid whirling of the card, the figures on each of its sides are presented with such quick alternations that they both appear at the same time, and thus a curious and amusing effect is produced. Many of the cards bear an epigram, conundrum, or motto, the point of which is explained by the change which appears in the figures during the rapid whirling of the card.'"

Here the vicar, having put in motion the card he was exa-

mining, cried out, "Magic! magic! I declare the bird is in the cage!"

"And what is the motto?" inquired Louisa.

The vicar read from one side of the card, "Why is this bird like an opposition member of the House of Commons who joins the ministry?"

"Because by turning round he gains a snug berth, but ceases to be free," was Mr. Seymour's prompt answer.

"The very reverse to what occurred in ancient Rome," gravely observed the vicar, "where, by turning round, the slave became free; for it appears from Persius that the form by which a slave was enfranchised consisted in clapping a cap on his head and giving him a turn on the heel."

"Please show us another card," cried Tom.

"But," said Mr. Seymour, "I have not yet read to you the conclusion of the inventor's address to the public, which contains a few good puns."

"Spare me the infliction of these!" cried the vicar. "I like your toy, but cannot discover the advantage of alloying amusement with such spurious wit, and of associating science with buffoonery."

Mr. Seymour, however, was relentless, and thus proceeded: "The inventor confidently anticipates the favour and patronage of an enlightened and liberal public, on the well-grounded assurance that 'one good turn deserves another;' and he trusts that his discovery may afford the happy means of giving activity to wit that has been long stationary, of revolutionizing the present system of standing jokes, and of putting into rapid circulation the most approved *bons-mots*."

"I am afraid the vicar sees small occasion for mirth in these jokes," observed Mrs. Seymour.

"Our subject has given even him a turn; let him alone, and he will soon come round," said Mr. Seymour.

The whole party, with the exception of Mr. Goodenough, burst into a roar of laughter; the vicar, however, did not relax a feature of his countenance.

As soon as this ebullition had subsided, Mr. Seymour produced another card from the box. On one side was depicted a watchman, and on the other his box. When the card was made to rotate, the watchman seemed to be comfortably asleep at his post. The accompanying epigram was as follows:

The caprice of this watchman surpasses all bounds;
He ne'er sits in his box but when going his rounds:
While he no sooner rests—'t is a strange paradox—
Than he flies from his post, and turns out of his box.

Another card was then shown, having on one side a horseman, and on the other a gate; so that when the card was put in motion the horseman appeared to be leaping over the gate. The rest of the subjects were now exhibited in succession, and the whole party, the vicar not excepted, were highly gratified with the amusement.

Mr. Seymour then proceeded to explain more fully the optical theory of the toy, which neither Louisa nor Tom as yet thoroughly understood. He told them that an object was seen by the eye in consequence of its image being delineated on the retina, or optic nerve, which is situated on the back part of the eye, and that it had been ascertained by experiment that the impression which the mind thus receives lasts about the eighth part of a second after the image is removed.

"It is, therefore, sufficiently evident," said Mr. Seymour, "that if any point, as a lighted stick, be made to revolve so as to complete the circle in that period, we shall not see a fiery point, but a fiery circle, because the impression made by it in every point of its circuit will remain until it comes round again to the spot from which it set out. But we will at once exemplify this fact by an experiment."

Tom was accordingly directed to procure a piece of stick and a candle, and as soon as they were brought into the room, Mr. Seymour ignited the end of the stick, and whirled it round, when a bright circle, without any intervals of darkness, was seen by the whole party.

"We have ample proof," continued Mr. Seymour, "of this power of the eye to retain impressions, and thus convert points into lines and circles, in the exhibitions of fireworks, which, in fact, derive the greater part of their magical effect from it."

"The pin-wheel is certainly nothing more than a fiery circle produced by the rapid revolution of a jet of flame," said the vicar.

"And the rocket," added Mr. Seymour, "is a column of light occasioned by the same rapid movement of a burning body in a rectilinear or curved direction."

"I perfectly understand all that you have said," observed Tom.

"Then you will not have any difficulty in explaining the action of the thaumatrope, for it depends upon the same principle. The impression made on the retina by the picture which is delineated on one side of the card is not erased before the picture which is painted on the opposite side is presented to the eye, and the consequence is that you see both sides at once. Or, you might put it in this way—that as the image remains the eighth of a second on the retina after it has been withdrawn from the eye, a revolution of eight times in a second will secure its uninterrupted continuance."

"On turning round the card," observed Louisa, "I perceive that every part of the figure is not equally distinct."

"Because every part of the card does not move with the same velocity," said her father. "The more remote are the parts from the axis of rotation, the greater their velocity. This toy will also exemplify another truth, namely, that the axis of motion remains at rest while all the parts revolve around it. Take the card and spin it between yourself and the window, and tell me what you observe."

"I see a dark line across the window, and, what is very strange, the other parts of the card appear transparent, for they do not obstruct the view of the window, as they would if the card were at rest."

"The dark line you see is the axis of rotation, which, being stationary, necessarily excludes the light; the other parts being in motion, do not remain a sufficient time to obliterate the image made on the eye by the window. It is true that the card disc passes between your eye and the light, but as it does not continue at any one point for the eighth of a second, there is no more apparent intermission of the light than what occurs during the winking of the eyes."

"You allude to the curious fact," observed the vicar, "that, although we are perpetually covering the eyeballs with our eyelids, we are not conscious of the intervals of darkness."

"The reason of which must be obvious from the explanation I have just offered," said Mr. Seymour: "the sensation of light is not exchanged for that of darkness in so short a period as the twinkling of the eye."

"I remember," said Louisa, "I used to be puzzled by finding that I could see the objects on the other side of a rapidly moving at [illegible] almost as distinctly as usual, and as if the train were trans-

parent, although the opaque portions of the carriages must hide the objects from view most of the time; but I now perfectly understand how it happens."

"But I must inform you," said Mr. Seymour, "that many other toys have been constructed in which the principle of the persistence of vision is made the means of producing amusing effects. I have obtained for you one of the most modern forms of these toys, which has received the name of the *Zoetrope*."

Mr. Goodenough explained that the name was doubtless derived from the Greek words ζωη, *life*, and τρεπω, *I turn*.

Mr. Seymour now produced the new toy from a box, which he had hitherto kept out of sight. The zoetrope consisted of a cylinder of thin metal, open at the top, and capable of revolving with great ease and regularity about its axis, by turning horizontally on a pivot in the heavy stand which was provided for that purpose. At equal intervals, in the upper part of the cylinder, were a number of narrow slits parallel to the axis of the cylinder, and extending nearly half-way down. A series of slips of paper, in length equal to the circumference of the drum, and in width equal to half its depth, contained sets of figures representing some movement, such as a man leaping, a girl with a skipping-rope, a juggler throwing balls, &c. The figures on each slip represented the particular movement in a number of successive phases corresponding to the number of slits in the cylinder. When one of these slips was placed round the interior of the lower part of the drum, and the figures were viewed through the slits while the instrument was in rapid rotation, the range of figures appeared to be stationary as regards the position occupied, but each figure appeared to be performing the same movements.

The instrument was placed on the middle of the table, and the whole party simultaneously viewed with great delight the curious movements apparently made by the figures. This novel toy, indeed, proved so attractive, that it was only after all the different slips had been examined that the juvenile party began to wish for an explanation of the strange effects.

"I perceive," said Tom, "that when one looks over the edge of the drum, the separate figures are quite indistinguishable; and I understand the reason of this, which is precisely the same as in the case of the circle of fire produced by whirling round the lighted stick. But I do not understand why the rapidly

moving figures should appear to remain in a row, and all performing the same actions, when they are viewed through the slits."

"I think you will soon be able to understand the reason of these appearances, by aid of the diagram (Fig. 25) which I have prepared. Here I have represented the zoetrope as if viewed from a point in the ceiling over its centre. The dark circle is the body of the instrument, and the spaces at 1, 2, 3, &c., are the slits. Your eye is supposed to be at E, and at the time the slit marked 1 is passing in front of your eye, let one of the figures be seen at 1′. Now, although the figure is moving rapidly, it will be actually visible for but a very short space of time, namely, while the slit 1 is passing in front of the eye, and during this time it will not appreciably have changed its position. But the impression on the retina of the eye, received during that short interval, is not obliterated; for if the drum is turned with sufficient rapidity, it remains until slit 2 is in front of the eye, which, in the meanwhile, has been receiving no further impressions from the figures, for the side of the cylinder, 1, 2, has been interposed as an opaque screen. During this interval, the figure before at 2′ has been advancing in the direction of the arrow, and at the instant that slit 2, coming in front of the eye, opens up a direct view of the figures, the various parts of 2′ are exactly in the position formerly occupied by the precisely similar parts of 1′. The retina, therefore, receives a renewed impression on exactly the same places as before. Similarly, when slit 3 is before the eye, the picture 3′ occupies the same relative place as the former ones, and so on. Hence, if the pictures were in every respect precisely similar, you would see an apparently motionless row of figures. But the figure on 2′, although in other respects exactly like 1′, differs from it in showing the action in its next phase. Thus, if the effect intended is to be a conjuror throwing up a ball, and 1′ represent the ball in his hand, 2′ will show the conjuror exactly as before, but the ball will be represented a little above his hand, and 3′ will show it still higher, and so on. The successive images impressed on

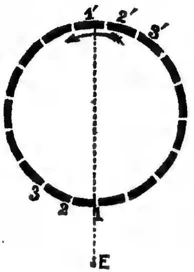


Fig. 25.

the retina will therefore convey the impression that the ball is changing its position."

"Your explanation also perfectly accounts for the somewhat jerky character which the movements present," observed the vicar.

"The figures," replied Mr. Seymour, "do not show us motion, but only give us the body in several different positions, and hence the illusion is most successful when those movements are suggested which in nature the eye cannot follow on account of their rapidity. This is why the subjects representing leaping, dancing, striking, falling, or other abrupt motions, have given us the most pleasure."

"Although you have told us," said the vicar, "that the impression lingers on the retina for about the eighth of a second, it appears to me that objects frequently linger on the sight for a longer period than that. I well remember seeing the flame of a candle for several seconds after it had been suddenly extinguished."

"There can be little doubt," observed Mr. Seymour, "that the duration of these impressions must be influenced by their intensity. But there is another very remarkable class of optical sensations which may persist for several minutes after the exciting objects are withdrawn. If we direct our gaze for about thirty or forty seconds towards some brightly-coloured object, keeping the eyes steadily fixed upon one point, so that the images of the object remain during that period of time depicted upon the same parts of the retinæ, we may, after the removal of the object, continue to see its shape with perfect distinctness for a longer or shorter interval."

"That would be very like seeing a ghost," exclaimed Louisa; "but I do not remember that anything of the kind you mention ever appeared to me."

"The only conditions required," replied her father, "are a certain amount of distinct contrast in the shape and colour of the objects, and a fixity of gaze, which the eye naturally seeks to avoid, and which in general, therefore, occurs only when the attention is intently directed to observe very small objects, and in such a case the spectral images I am speaking of may present themselves unheeded. But by a simple effort of will to keep your gaze riveted on a single point, you can at any time summon up these phantasmal forms. I will now give you some very

simple shapes on which to try the experiment. Here is a sheet of paper, in the centre of which is a circle about the size of a shilling, painted with the bright colour which is called emerald green, and here is the ace of hearts from a pack of cards, and here again I lay the vivid scarlet petal of this flower upon a piece of black cloth. And now you must place yourselves so that each may have one of these objects about two feet from his face, and with a good light falling upon the object."

The arrangements were quickly made, and each of our young friends was soon staring resolutely at the coloured object before him.

"I see," exclaimed Louisa, "a strange sort of greenish light apparently flickering round the margin of the heart."

"You must, however, still direct your eyes to the same point at which you first looked; for if you should move them in order to observe the margin of the figure, our experiment will probably not succeed."

Louisa now complained of a sensation of weariness or strain in her eyes.

"That shows that you have looked long enough at the objects," said Mr. Seymour; "and I must ask all to suddenly direct your eyes towards the ceiling."

"Oh, I declare!" cried Louisa, instantly, "I see the heart on the ceiling with perfect distinctness; but it is of a beautiful green colour, and not red."

The rest of the party did not succeed in this their first attempt—probably, as Mr. Seymour explained, in consequence of unconscious movements of their eyes; but after a few trials this difficulty was overcome by all but John and Rosa, and the appearance of the phantom shapes on the ceiling was the source of much amusement, various things being made the subjects of the experiment. Thus, for example, when the cover of a book, bound in bright green, with the title stamped upon it in gilt letters, was used, the spectral image showed a rose-coloured ground, on which the letters, and even the smallest portions of the gilt ornaments, could be leisurely examined, just as if the actual object were before the eye, only they now appeared of a bluish colour, and much darker than the ground.

"But what enormously large letters they seem!" cried Tom. "I cannot understand why the images should appear magnified, or why they should have colours so different from the objects."

"These images, there is good reason to believe," replied Mr. Seymour, "are due to a cause which is, in a sense, the opposite of that concerned in the persistence of the impressions we have seen exemplified by the zoetrope; for these ocular spectra are attributed to the exhaustion of the sensibility of the retina."

"To the exhaustion of its sensibility!" exclaimed Louisa: "how can that possibly be?"

"It is quite within everybody's experience that a powerful impression made on any of our organs of sense impairs for a while the sensitiveness of that organ for less powerful impressions of the same kind. For example, if you have tasted something intensely sour or bitter, you are unable for a little while afterwards to perceive the like savours in other things which possess them in only a slight degree. Now, a bright red colour in an image which is depicted for a few seconds on the same part of the retina, deadens the sensibility of the nervous fibres there for perceptions of red colour. Consequently, if a mixture of variously coloured rays be allowed immediately after the removal of the red image to enter the eye, the perception of red being weakened over the space just before occupied by the image, another image will appear formed by the practical absence of red, and therefore deriving its tint from the rest of the colours."

"I quite understand this explanation," said Louisa, "except that I cannot imagine how there can be any red colour in the ceiling or other white object."

"I do not wonder at your difficulty; but I intend to make colour the subject of our next conversation, and I hope you will then be able perfectly to convince yourself that white is actually produced by the mixing of all the colours of the rainbow. After that you will, I hope, have no further difficulty in explaining the spectral images we have been amusing ourselves with. But we have yet to learn how it happens that these images appear so much larger than the objects. It is because in looking at the ceiling you have, so to speak, referred to its surface the image you saw, and as at that distance an object must be much larger than one on the table, in order that its image should occupy the same space on the retina, so, on the other hand, in referring the impression to the ceiling—I mean in thinking of it as of something on the ceiling—the magnitude is judged of according to the same standard. If, instead of looking upwards, you turn

your eyes to a piece of blank paper close at hand, you will see the same spectral image on that apparently, and it will not be judged to be large, simply because it is supposed to be at only a short distance from the eye."

Mr. Seymour, in concluding this conversation, mentioned that he would the next time take the opportunity of showing them some pretty experiments in colours; but these must be deferred until a bright sunshiny morning presented itself.

Now, it so happened that the next few days were overcast, and therefore, in the absence of events at the Lodge, we can opportunely look in at Ivy Cottage, to see how the major is settling down in his new abode.

The reader will naturally be anxious to know what brought this stranger to Overton. It was simply because, being desirous of passing a few months in some very quiet place where the climate was mild and equable, he had learned that the Cottage was to let, and had heard such an account of the locality from his trusty valet, Jacob Thompson (who was, in fact, a native of the district), that he at once determined on taking the place for twelve months.

"Well, Jacob," said the major, a day or two after their arrival, "I like the look of this place; I like the country: it is beautiful, Jacob, and the air will suit me very well. I think you said the name of the proprietor of the Lodge was Seymour?"

"It is, sir," replied Jacob: "T. Seymour, Esquire, J.P."

"And what other neighbours shall we have, Jacob?"

"Why, an 't please you, major, there is Mr. Goodenough the vicar, and the folks about here do like him uncommon; but he must be a queer sort of parson if it is true what an old acquaintance told me that I met at the 'Devil and Bag of Nails.'"

"Do you mean at the village blacksmith's?"

"The village blacksmith! Lord love you, it is the sign of the village public house."

"Then it is a plaguy odd one! But go on with your story."

"Well, as I was saying, major, my friend told me that the vicar has all sorts of *curosities* in his parlour—things with grinning faces, shapes of dogs with three heads, broken pots, and funny-looking fiddles; and besides this, he said he is so fond of all manner of strange antics."

"Fiddlestick! stuff and nonsense! who ever heard of a parson fond of antics! You mean, Jacob, that he is devoted to *antiques*

—not *antics*. But, tell me, are there any other agreeable persons in this village?"

"There is Dr. Doseall," replied Jacob, "and there are a lot of old maiden ladies."

"Old maids!" exclaimed the major, who had a peculiar antipathy to this class of the gentler sex.

Yet had the Fates decreed that on that very afternoon the gallant warrior should undergo the ordeal of a visit from two of the inquisitive sisterhood, Miss Ryland and Miss Sowerby, in pursuance of their project of drawing out from the major himself as many circumstances of his personal history as could be obtained by the exercise of their practised skill in directing conversation to the accomplishment of such designs. As in these veracious chronicles we desire to place before our readers only well-established and unquestioned facts, we shall not make any categorical statement concerning the pretext under which these ingenious, rather than ingenuous, ladies called at Ivy Cottage. The records are at best but extremely vague upon this topic; nevertheless—like the question of what song the sirens sang, or what name Achilles assumed when he hid himself among women—the matter, though puzzling, is not beyond all conjecture. It is probable that the subscription list of a local charity supplied the occasion for the call; and perhaps the conversation took a more expansive turn when, as it is said, one of the ladies having recollected the name of some very distant relative of hers who had been in the Indian military service, it was found that by a curious coincidence the major had been well acquainted with him.

The ladies enumerated the several families in the neighbourhood, descanted upon the pride of the Seymours, the eccentricities of the vicar, the wonderful cures of Dr. Doseall, the curious inventions of Sam Tickle, the critical acumen of Jeremiah Drawley, the parish clerk; in short, the poor major was attacked by volleys of words more incessant than the grape-shot which the Sikh batteries had poured forth against him at Ferozeshah. At length, however, the assailants having discovered that the citadel was not to be taken by assault, the fire began to slacken. The ladies withdrew, much disappointed in the result of the attack, but not wholly without material which could be elaborated into very retailable gossip.

Upon their departure Jacob was angrily summoned into the

major's presence; for by this time the gallant officer was fully charged with indignation.

"Jacob," exclaimed he, "you must take care that I am not exposed to a repetition of this annoyance. Should any of the spinster tribe honour me with another call, inform them that I am from home, or tie up the knocker, and tell them that I am sick—dead—buried! Say anything, but spare me such another visitation!"

Had occasion required, Jacob would doubtless have acted in strict accordance with the major's injunctions, as he always considered it his duty to obey orders with military exactness. Yet the old adage of "like master, like man," was not exemplified in the case of the major and his valet; inasmuch as a little incident, which occurred on the very next day, showed that the valet by no means shared his master's antipathy to spinsters. For when Jacob, in one of his visits to the village, quite unexpectedly met with an old acquaintance of that class whom he had not seen for many years, he was greatly delighted, and very cordial greetings were exchanged. From the mutual explanations which followed, Jacob learned that his friend was and had been for many years our vicar's housekeeper—for it was no other than Annette. It was perhaps from a tender and deferential regard for the strong prejudices of his master, aggravated as they had been by the incidents just related, that Jacob refrained from mentioning to him the circumstance of his acquaintance with Annette. But the reasons which could have determined Annette to maintain a similar reticence on the same subject towards the vicar, with whom she was usually very communicative, can be divined only by those who are better acquainted than ourselves with the motives which govern female breasts.

CHAPTER VI.

Of colours changing from the splendid rose
To the pale violet's dejected hue.

A morning came when the sun shone gloriously, and the children were delighted to know that they should that day be able to learn something of the laws by which the beautiful tints of earth and sky are produced—how the sunbeam clothes the flowers with their lovely dyes, and arrays the landscape in its variegated hues. They were summoned to the library at the accustomed hour, and found that Mr. Seymour had again caused that apartment to be darkened by having all the shutters closed. But through the hole in the shutter of the eastern window streamed a small direct beam of intense sunlight.

"I am about to repeat for your instruction," said he, "a very noted experiment of Sir Isaac Newton's. You see I have here one of the triangular pieces of glass which hang on the lustre in

the drawing-room, from which I have detached this one, to serve in place of a more perfect piece of apparatus. Now, Tom, do you hold this piece of white cardboard perpendicular to the beam of light, for I wish everybody to observe the bright circular spot of white light, which you know is an image of the sun, by reason of the same laws which gave us yesterday the image of the rose, when its rays passed through a small opening. Observe what happens when I place the triangular piece of glass lengthways over the opening in the shutter. The white spot is gone from the cardboard; but if Tom will hold it a little higher, you will see that we have got something else instead."

"What splendid colours!" cried several voices simultaneously, as the prismatic spectrum fell on the cardboard.

Mr. Seymour explained that the elongated patch of varied colours was the image of the sun drawn out by the glass refracting the differently coloured rays of the sunlight in various degrees.

"You have, no doubt, been accustomed to think of the light of the sun as something simple and uncompounded, whereas this experiment is sufficient to show that every ray of sunshine consists of an infinity of differently coloured rays, which the little piece of glass has the power of separating from each other."

Louisa here inquired how many colours there might be in the image on the cardboard.

"It is usual," said Mr. Seymour, in reply, "to reckon seven distinct colours in the 'solar spectrum,' as this image is called. The names given to these are red, orange, yellow, green, blue, indigo, and violet."

"I see all these!" cried Louisa.

"But observe that they graduate into each other, so that there are portions of the spectrum which cannot be said properly to correspond with any one of these names. You observe a colour between the green and blue, which cannot be called by either name separately. The orange is really a similar transition tint between the yellow and the red; and although we have a distinct name for this colour, we have none for an indefinite number of intermediate hues which the eye readily distinguishes; so that the colours are not in reality seven, but are infinitely numerous."

Fanny asked if the colours did not in some way come out of the glass, for she had often seen colours like these in the lustre.

"The colours you have seen, my dear, are formed precisely in this way, and if you placed your eye in the position of the cardboard, you would see such colours on looking towards the glass. But you will presently be convinced that the colours cannot be derived in any way from the glass, but belong to the light itself; for you will see that when we mix the colours together again, we shall reproduce colourless light; but although there are means of doing this with the coloured rays you see on the cardboard, I will obtain white by mixing colours in a simpler way. Before I open the shutters I wish you to observe that the red end of the spectrum is nearer to the position of the unrefracted image of the sun; hence the red rays are spoken of as the 'least refrangible,' and the violet as the 'most refrangible.'"

The shutters having been opened, Mr. Seymour produced a circular disc of cardboard, on which sectors of vividly coloured papers had been pasted of the colours indicated in Fig. 26, which also shows by the numbers the sizes of the sectors — the entire edge of the circle being supposed to be divided into 360 equal parts. It was explained that the space taken up by each colour was assigned so that the disc might have as nearly as possible the same proportion of each colour as the solar spectrum. A pin having been put through the centre of the disc, it was thus attached to a piece of wood, and made to rotate rapidly in an upright position by a touch of the finger. When the disc was in very rapid movement, the colours all became invisible, and the face of the disc appeared to be light grey, almost white; to the no small astonishment of the juvenile party.

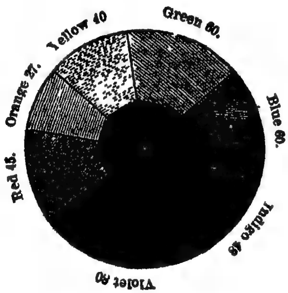


Fig. 26.

"You will all understand from our former experiments with the thaumatrope that each colour in the revolving disc leaves its own impression on the retina; so that if only the red sector were present, we should have the appearance of a paler but uniformly red disc, and so on. And as the same is true of each of the colours, the result is that the effect of one is covered by that of

the other, so that the colours are virtually mixed in the eye, and they produce, as you see, the sensation of white."

This composition of white light by variously coloured rays was perfectly understood, and greatly delighted the youthful spectators; but as the effect required a very rapid spinning of the disc, which was only maintained a very short time, Mr. Seymour adopted an expedient which permitted a more leisurely examination of this interesting and instructive phenomenon. He attached the disc to the upper part of a large humming-top, and when this was set in motion, the requisite rapidity was maintained for several minutes. Mr. Seymour now presented the children with several "colour-tops," as they are called, which he said would instruct them in the formation of various tints by the mixing of different colours in precisely the same manner as in their experiment of the coloured disc.

Here we may mention that Tom subsequently constructed by himself a disc on a larger scale, in which the alternation of the coloured sectors was repeated several times; and by making experiments with various proportions of the coloured papers he used, he succeeded at length in so adjusting the colours, that the resulting tint was very nearly white, or, at least, no one colour could be said to predominate. Tom learnt on the present occasion that the reason why the impression resulting from the mixture of the tints was not perfectly white was partly the difficulty of proportioning the coloured surfaces, but chiefly because no pigments we possess are of a perfectly pure colour. And in reply to a question of his as to whether red, blue, yellow, &c., paint would, when mixed together, form white, Mr. Seymour told him that the mixture of pigments introduced another class of effects.

"If you will arrange one of these colour-tops so that red and green may be mixed in the eye, you will obtain a neutral or grey tint; but if you take a piece of transparent red glass, and put over it a piece of green glass, you will find, on looking through the two, that you have not added green to red, but that the light which passes through consists of those coloured rays which can pass through both glasses; and as a glass of a pure red colour would stop all but red rays, and a similar green glass all green rays, the superposition of two such glasses would be opacity. But the colouring matter in glass, although allowing rays of a certain refrangibility to pass more abundantly, always permits

a certain amount of other rays to pass also. In the mixture of pigments, the resulting tint usually depends in a great part on the light passing through the several particles, as if through different coloured glasses; hence it is impossible to produce an approach to whiteness by such mixtures of pigments."

Louisa asked if the colours of all objects were derived from the light.

"From the light which falls upon them, of course," replied Mr. Seymour. "Ordinary light consists, as you have just seen, of numberless coloured rays blended together, and when such light falls, let us say on a leaf, all the rays, except chiefly the green ones, are absorbed, destroyed, or in some way disposed of, so that they cease to exist as rays of light, while the green rays are scattered abroad by irregular reflection from the object, and so reach the eye."

Louisa said she had heard of complementary colours, and wished to know what was meant by the phrase.

"If," said her father, "you select any part of the spectrum, say the red portion, and if that colour could be removed, and the remaining rays mixed together, the tint they would produce would be called the complementary of the red—that is, together with the red it would complete the spectrum, and its mixture with the red would reproduce white light. The accidental or spectral colours you witnessed the other day were, in every case, of the colour complementary to that of the object. Thus you cannot look at a green object without giving your eyes in consequence an extra sensitiveness to the red rays, and *vice versâ*. But here are some pieces of coloured glass, and by looking at the window through one of these for a few seconds, on removing the glass you will see the light apparently tinged with the colour of the complementary; look through the green glass if you would afterwards see everything *couleur de rose*. You thus perceive that an eye which has been looking at a green colour becomes very appreciative of red, perhaps because the nervous apparatus of the eye has become fatigued with the stimulus of green, and less sensitive to its presence; hence a red colour appears more vivid if we look at it immediately after gazing at green. This kind of effect has been termed by M. Chevreul, who subjected these phenomena to a systematic scientific examination, *successive contrasts*, while to the kindred phenomena I am about to show you he has given the name of *simultaneous*

contrasts. When I have arranged some pieces of coloured paper on the table, I will ask you all to tell me your opinions about certain tints."

Mr. Seymour laid a large sheet of very intense deep blue colour on the table, and also a sheet of extremely vivid orange; then dividing a sheet of ordinary note-paper, he placed a piece in the middle of each of the large coloured sheets. Calling the spectators now to approach, he asked them to pronounce what difference, if any, existed in the colours of the pieces of note-paper.

A perfect chorus of voices unhesitatingly asserted that the one paper was yellowish, and the other pale blue.

"Would you be surprised to learn that these are portions of the same piece of note-paper?"

"Impossible! the colours are so very different."

The logic of facts soon dispelled their doubts, for changing the places of the paper changed their tints also; and experiments with red and green papers showed similar results, for one made the white paper appear greenish, while the other seemed to impart a distinct rosy tint.

"Why," cried Mrs. Seymour, "I really believe now that a pale face might be made to appear quite rosy by bringing near it bright green in the head-dress or drapery; only this is entirely the opposite of what the milliners tell us, for they declare that a pale face should have rosy tints near it in order to give colour, and they suppose that the colours in the head-dress are reflected on the face of the wearer."

"I believe there was a time," said Mr. Seymour, "when ladies' bonnets were of such dimensions, that they might reflect some colour on the face, but now-a-days it can no longer be a question of the head-dresses reflecting colour, for they are placed much too far from the face for that. But even supposing that a rose-coloured bonnet could reflect its hue on the face of the wearer, the parts of the face lighted up—for I presume you need not be told that such reflected light would only fall upon parts of the face—these rosy parts, I say, would of themselves cause the other parts which did not receive the rosy reflection, to appear greenish by contrast."

"I quite see how that would be the case," said Mrs. Seymour, "from the experiment you showed us with the white paper."

"The surprising thing is," said Mr. Seymour, "that people

should every day be looking at such effects and not seeing them."

"I do not at all understand what you mean now," exclaimed Louisa.

"I mean it is extraordinary that people should have these appearances before their eyes, and have their judgment influenced by them, and yet fail to recognize the laws of contrast in colour. Even painters, who, it might be supposed, would perceive the power of contrast, seem in some cases either to be unacquainted with it, or to avail themselves of it unconsciously. It is related of Eugène Delacroix, one of the most famous of the modern French school of artists, that, desirous on one occasion of painting a drapery of a lively yellow colour, after several unsuccessful attempts, he determined to hasten to the Louvre in order, if possible, to discover how Rubens and Veronese managed to obtain such beautiful brilliant yellows. He accordingly ordered a carriage to be called, and one was brought to his door. It happened that at that period the public carriages in Paris were painted of a bright canary-yellow colour, and as Delacroix was about entering the vehicle, he stopped, for he observed to his surprise that the illuminated yellow of the carriage imparted the complementary violet to the shades. He had now discovered the object he was seeking, and therefore he dismissed the cab, returning to his studio, where, tinting the shades of his drapery of the complementary colour, he attained the brilliant effect upon which he had set his heart."

"That story reminds me," said Mrs. Seymour, "of an incident I remember reading in Eckermann's 'Conversations of Goethe.' He says that one beautiful day in spring they were walking in a garden where there were masses of yellow crocuses in full flower, and it was noticed, while observing these, that wherever the eye caught a glimpse of the soil, the latter appeared as patches of deep violet among the crocuses. But have you anything more to tell about the philosophy of bonnets, in the colour of which I suppose we should endeavour to obtain the contrast most favourable to the wearer's complexion, rather than to supply the hue in which the face is deficient?"

"Precisely," replied Mr. Seymour, "and I think a trial will convince you that this is the proper principle for guiding you in the selection of colours. You may be interested in hearing M. Chevreul's remarks as to the colours most suitable for various

complexions. He says that for the ladies with fair hair and fair complexions, a black bonnet with white, rose, or red flowers, or white feathers, is not unsuitable; a white bonnet of gauze, crape, or lace will do for any complexion; and that blondes may have white, or rose, or preferably blue flowers in it; while brunettes should give the preference to red, orange, or yellow accessories. A green bonnet is advantageous to fair or rosy complexions, and may be trimmed with white or rose-coloured flowers. A light blue bonnet is suitable to the light-haired type only, and may be ornamented with white flowers, or in some cases with yellow or orange flowers, but not with violet flowers. A pink bonnet must not be too close to the skin, especially in the case of brunettes, for whom rose-red or cherry colour is suitable; but if, in any case, the hair does not produce sufficient separation, the distance of the skin from the rose colour may be increased by the introduction of white or green; and for this purpose a wreath of white flowers with abundance of green leaves has a good effect. Yellow bonnets suit brunettes very well, and receive violet or blue accessories with advantage. A violet bonnet does not improve complexions of any type, and is admissible only when separated from the face by the hair and by some yellow accessories."

Mr. Seymour had just concluded the above discourse when the door opened, and the vicar entered the study.

"My dear friends," exclaimed Mr. Goodenough, "I have been most provokingly detained by the maiden ladies, or I should have been with you, as I had promised, at a much earlier hour. Upon my word, Mr. Seymour, their tongues are like aspen-leaves, never at rest."

"You may then congratulate yourself," observed Mr. Seymour, "that you have escaped. But what has put them in motion? Some fresh breeze, I suppose."

"They have been amusing me," replied the vicar, "with the birth, parentage, education, and adventures of a Major Barker, who has just taken up his abode at Ivy Cottage. After this topic was discussed, they reverted to the old story of the rights of women, and told me in pretty broad terms that my contumacy on that subject should be visited by all the evils their spleen could devise."

"Their discourse, then," said Mr. Seymour, "was just as *broad* as it was *long*."

"What! at your old vice again?"

"Well, I shall doubtless soon meet with my punishment; I am sure to receive poetical justice from your hands; a *line* at this moment hangs over me: eh, my friend, do you understand me?"

Mr. Goodenough either did not comprehend, or would not notice, this last *jeu d'esprit*, but proceeded to state that he had no sooner escaped from the aforesaid quicksands than he encountered Polyphemus. Our readers may, perhaps, wonder who this Polyphemus could have been; we must, therefore, inform them that Mr. Goodenough, whose ideas were always tinctured with classical colouring, had bestowed this appellation upon Dr. Doseall, because, as he said, his practice was, like the Cyclops, strong, but blind; and Mr. Seymour declared that the similitude was even more perfect than the vicar had contemplated, for he observed that the doctor certainly fattened upon the unhappy victims who fell within his clutches. With all our respect for the liberality of Mr. Seymour and the kindheartedness of the vicar, we must, in justice to this respectable son of Esculapius, express our disapprobation of so undeserved a sarcasm. We admit that Dr. Doseall, after the example of other celebrated physicians, had one sovereign remedy, which he administered in every disease. But what of that? He was often successful in his cases—that is to say, his patients sometimes recovered after they had taken his physic; and is not that the test conventionally received in proof of the skill or ignorance of greater physicians than Dr. Doseall? Nor can we persuade ourselves into the belief that a doctor who faithfully adheres to one single remedy is less likely to be right than those restless spirits who are eternally coquetting with all the preparations of the Pharmacopœia, without ever remaining steady to any one of them. It has been truly remarked that the clock which stands still, and points steadfastly in one direction, is certain of being right twice in the twenty-four hours, while others may keep going continually, and as continually going wrong. Being ourselves no doctors, we merely throw out this hint for the consideration of those who are learned in such matters. But we beg the pardon of our readers for this digression.

"Well," said Mr. Seymour, "I am, at all events, rejoiced to see our Trojan in safety after such perilous adventures, and I hope that he is now prepared to set sail again with us on a new

voyage of discovery. I have been engaged," continued he, "in explaining the effects of contrasts of colours."

"I am sorry that I have not had the advantage of hearing your discussion; but perhaps I may supplement the scientific information you have conveyed to my young friends and playmates by a word on the symbolic meanings of colours in the Christian iconography of the middle ages. They must know, then, that in Christian art each of the colours—white, red, green, and violet—had a distinct signification, or was appropriated to special purposes. White was the colour expressive of divine truth, and this colour was given to the robes of the Saviour and saints and angels, and to symbolical representation of any of the three Persons of the Trinity. Thus, in representations of our Lord's baptism, the dove was invariably of a pure white colour. So also, Clement of Alexandria calls truth the 'lily of speech.' Red was always indicative of some act of Divine love: thus the crosses which you see in old stained glass windows are always red, in allusion to the redemption. Green, again, was the sign of life, youth, vigour; and you may observe in the remnant of the old glass which we still retain in the east window of Overton Church that this is the colour of the tunic of St. John the Evangelist. Violet always symbolizes penitence, and when in a mediæval window you see an angel represented as dressed in a violet robe, you may be sure that the artist intended to convey the idea that the mission of that heavenly messenger is to bring sinners to repentance."

"These are very interesting and curious observations, vicar," said Mr. Seymour; "and they serve to explain what I have noticed in the churches of some continental countries, which I have observed on certain occasions to be decorated with crimson draperies, and on others with violet; and portions of the vestments of the officiating priests, I have noticed, have sometimes been of one, sometimes of the other colour."

"I believe," replied the vicar, "that you see the scarlet displayed on the high festivals of the Church, while on penitential days the violet takes its place."

"I think it is Goethe," said Mrs. Seymour, "who so strongly contends that colours have in themselves a moral and intellectual influence; that bright colours gladden the spirits, while sombre hues dispose the mind to grave thoughts."

"Such effects as you mention," replied Mr. Seymour, "are

undoubtedly produced; but whether by any inherent power in the colours themselves, or merely in consequence of association of ideas, it is not easy to say. It is remarkable, however, that in every language many of the words which represent states of mind are also applied to colours. Perhaps colour presents the most striking examples of the relativity of our sensations. Take the case of our feelings of the *beauty* of colours: the experience of every person tells him that the state of his own mind is the greater factor in the perception. Thus it happens that a tint may cease to appear beautiful when it has become familiar. The blush of the newly-opened rose amid the green leaves, and the blue of the forget-me-not or the gentian, for the rareness of its colour among plants, appear exquisitely beautiful; but who would wish to sit in an apartment where everything, walls, ceiling, carpet, furniture, was literally of a rose colour, or where every surrounding object was dyed with a uniform cerulean hue?"

"But, papa," said Louisa, "is it not true that some colours have a more exciting effect on the eye than others—that scarlet, for instance, dazzles the eye, and green gives repose?"

"The supposed effect of scarlet is explicable by its comparative rarity in nature, and I doubt not but that, if all the green and red changed places, we should be as much attracted by green as we now are by red, and would attribute to it the same exciting effect; while the repose you speak of as belonging to green would seem to belong to the scarlet foliage, to which our eyes would be so much accustomed."

"Yet I think," said the vicar, "that there was some sort of propriety in what the blind man, mentioned by Locke, said about scarlet, namely, that it was like the sound of a trumpet."

"That story has been absurdly cited," replied Mr. Seymour, "to make it appear that the impressions of one sense can be represented or known by the impressions of another. Now, it would not be difficult to trace out the connection which makes it appear to one as in some way appropriate to represent scarlet by the sound of a trumpet; and the blind man was, probably unconsciously to himself, led to the comparison by the very same chain of ideas that I am about to suggest. The sound of a trumpet is more closely associated with soldiers and war's alarms than with anything else. Well, it so h ppens that scarlet is the distinctive colour of the military unifo n in this country, hence the ideas and even the words "scarle and "trumpet" acquire

a necessary association, even though we may be unconscious of the intermediate links."

"There are also," said Mrs. Seymour, "strange stories about blind people distinguishing between different coloured cloth by touch."

"No doubt," said her husband, "the sense of touch becomes in blind persons more delicate and discriminating than in persons who have their sight; and the alleged distinction of colours is easily explained by the difference of texture which different dyes may produce on stuffs, and which an extraordinarily acute sensibility of touch might discriminate. And now let me propose a conundrum, of which these stories of blind men remind me."

"Oh, yes, let us have it; I am sure we shall guess it!" cried several voices.

"It is this: *A blind fiddler had a sister, but the blind fiddler's sister had no brother.*"

Some vague attempts on the part of the younger members to explain the enigma by supposing that the blind fiddler's brother was dead, &c., were seen to be inconsistent with the terms of the statement; and this time both Tom and Louisa failed to have a solution ready, until the vicar remarked that it would be impossible for the statement to be enigmatical in such languages as Latin, French, or German. Upon this hint the solution flashed upon Louisa's mind, as it doubtless will upon that of the reader.

After this the children were dismissed to follow their own pastimes in their own way, and Mr. Goodenough announced that he should depart for the purpose of visiting the new resident at Ivy Cottage, for he considered it his duty, as vicar of the parish, to call upon every respectable stranger who might come to reside at Overton.

It is our duty to follow the vicar to Ivy Cottage, as the interview which took place on that occasion will make the reader acquainted with circumstances relating to the development of our story.

"Mr. Goodenough," said the major, as he advanced to meet his visitor, "I feel myself obliged and honoured by your kind attention. As a perfect stranger here I scarcely could have expected this prompt civility. I like your village, and in this retired spot, far from the madding crowd, and the artificial life

of cities, I hope to pass a few months quietly. Am I rightly informed that the neighbourhood of Overton is no less healthy than it is beautiful?"

"So says Dr. Doseall," observed the vicar; "and upon this point I am not disposed to question either his judgment or sincerity."

"I had scarcely entered into possession of this tenement," said the major, "than I had to encounter a brace of she-dragons—excuse the bluntness of an old soldier—who evidently had come to inquire into the circumstances and object of my intrusion into your pleasant village."

"She-dragons! Intrusion! Why, what can you possibly mean, major?"

"In plain terms, then, I received a visit from a couple of inquisitive, and I must add, impertinent, old maids."

"Miss Ryland, I presume."

"Yes; and a Miss Sou—Sourboy—I think that was the name of her companion."

"And may I ask what might have been the topic of their discourse, as it seems to have so greatly disparaged them in your opinion?"

"Everything and nothing: their tongues were like race-horses, which always run the faster the less weight they carry. But I crave your pardon. I am, perhaps, wrong in forming a prejudice from so transient an acquaintance, and still more culpable in giving expression to it; but rather than suffer another half-hour in their presence, I would——But pray be seated: I am a man of no ceremony, as you doubtless perceive: I hate it, and never suffer it in my presence. With this understanding, I am sure that you will not take offence at a question to which I am anxious you should give me an answer. Are you, my dear sir, as I have just reasons for supposing, an antiquary?"

"I am undoubtedly attached to pursuits which might have favoured such a report."

The major then mentioned the representation of the vicar which his man Jacob had given, and at this the vicar was not a little amused.

"Then," continued the major, "Jacob reported that your village inn rejoices in the very curious sign of 'The Devil and the Bag of Nails'! These confounded nails have been sticking in my head ever since; for I cannot understand what the devil

could be doing with a bag of nails, unless he were exhibited as presenting his customers with nails, in reference to the old adage, 'Every glass of spirit is a nail in your coffin.'"

"I much fear," replied the vicar, "that if the adage has any truth in it, the coffin of more than one individual in our village will be constructed entirely of that useful article of ironmongery. But the sign is not quite so uncommon as you seem to suppose; it was originally, 'Pan and his Bacchanals,' but by a very natural transition, the figure of the sylvan deity has passed into that of the evil tempter, while the word 'Bacchanals,' by one of those verbal corruptions so common in all languages, has been converted into the 'bag of nails.'"

"Your explanation, vicar, is far more plausible than mine; and although it does not carry along with it so useful a moral, it has the merit of being more classical."

The vicar now begged to make an inquiry, which he trusted would not be considered as a——

"Fiddlestick!" interrupted the major: "have I not told you that I am a man of no ceremony—that I despise it, and cannot endure it in my presence? Put your question, and you shall receive the best answer I can give to it."

The vicar's inquiry was simply a question as to whether the major had not been a student at Trinity College, Cambridge, as he remembered the name, and thought he even recognized some features——

"Bless me! I certainly was of Trinity; and now, I declare, if you are not one of the fellows I first met at that curious party poor Jorkins gave—he called it a *symposium*—just before I left Cambridge, when we had such queer messes, exactly after the supposed manner of the ancients."

The vicar well remembered the occasion, and much conversation followed this mutual recognition; for the circumstance of having thirty years before been a short time at the same University, and of having there, perhaps, two or three times passed a few genial hours in the same circles, sufficed to make these two gentlemen feel additional cordiality towards each other. The major briefly related his history to the vicar thus:

"My father having died very shortly after my admission at the University, I became dependent upon a rich uncle, whom I had scarcely seen, and who was not even on speaking terms with the family. On the decease of my father I received a formal

letter of condolence, with a qualified assurance of assistance, provided my conduct should justify his patronage: he concluded by a long lecture on the vices of youth, and the terrible extravagances into which they were so liable to be betrayed. I confess that from the style and spirit of this letter, I did not augur favourably; but I was happily mistaken. My extreme frugality won his heart; he found that his means were not squandered on a barren soil. To cut my story short, our connection soon ripened into attachment, our attachment into affection, and at his death I found myself in possession of his whole fortune. I entered the army and followed its fortunes, and I may on some future occasion give you an account of my military adventures. At present suffice it to say that I soon became ardently attached to my profession, and have seen as much active service as most persons of my age; and here I am, an old bachelor, with no one to care for me."

"Have you, then, no relatives living?" asked the vicar.

"I have not. The only sister I had contracted an unfortunate marriage after I left England, and is now dead. You are surprised that I should never have married? My answer will be short, and I trust satisfactory. I met with an early disappointment—inquire no further."

The major here ceased. The vein of melancholy which had pervaded this part of the story greatly affected the vicar, who now took his departure, having obtained a promise from his newly acquired friend that he would shortly return his visit, and examine the collection of antiquities upon which Mr. Goodenough so greatly prided himself.

CHAPTER VII.

> A thousand fantasies
> Begin to throng into my memory,
> Of calling shapes, and beckoning shadows dire,
> And aëry tongues that syllable men's names
> On sands, and shores, and desert wildernesses.

AT the period to which our story relates, the seclusion of Overton had never been disturbed by even the neighbourhood of a railway; nor, indeed, is there at the present time any immediate probability that the echoes of the rocky glen in the grounds of Overton Lodge will ever be awakened by the shriek of the passing locomotive. None of the great trunk lines go near the place. The nearest station is at Redminster, a quiet, sleepy little town, seven miles from Overton, and with little to attract the notice of a tourist, save the ruin of its once famous abbey. Even Redminster has had to content itself with a branch from the main line, and but few trains yet stop at the Redminster

Junction. If, therefore, any reader should desire to visit the vicinity of Overton, and view for himself those picturesque charms which we have hinted at, rather than described, we warn him that he may find a little more than the usual difficulty in availing himself of the guidance of *Bradshaw,* in whose crowded page the Redminster Branch does not figure conspicuously. This explanation of the position of Overton will serve to remove any suspicion which—from the absence of any mention of the station, or reference to the arrival of our personages by the express—might arise in the reader's mind that he is not perusing a story of real life: place, England; time, second half of the nineteenth century.

About four o'clock one afternoon the sound of the porter's bell, and the rolling of carriage-wheels, announced the approach of some stranger to the Lodge. It was Miss Villiers—yes, gentle reader, it was the heroine of our story, with whom you are, doubtless, burning with impatience to become acquainted; and were this a romance, rather than an instructive history, we should at once charge our pencil with the most glowing hues, and proceed to colour the outline which your fancy must have already sketched. We might describe the symmetry of her form, but what language could convey to the mind's eye the witching graces which surrounded it? we might depict the features of her countenance, but how could we catch and fix the varying expressions which lighted it up with the magic flow of intelligence? We shall, therefore, leave the reader to the exercise of his own imagination.

During the evening the vicar joined the party. Mr. Seymour mentioned to Miss Villiers the attempts which he was making to excite in the minds of his children an interest in scientific knowledge; and said that, in some sort of relation to the subjects which were about to occupy their attention, he had just composed an enigma, which she might be amused to hear the juveniles discuss.

"A riddle!" exclaimed Louisa; "how delightful! Pray read it, papa, and let us try to discover its meaning."

Her papa then produced a paper, and read as follows:

"Mortal, wouldst thou know my name,
Scan the pow'rs I proudly claim.
O'er this globe's capacious round
With fairy sprightliness I bound;

To ev'ry clime, to ev'ry soil,
With equal hand I give my toil.
O'er sea and land my power extends,
To ev'ry herb my care descends.
Did I withhold my vital breath,
Nature's forms would sink in death.
When confin'd, or swiftly driven
By angry spirits in the heaven.
My wrath in thunders I make known,
And Discord claims me as her own.
'T is love of freedom makes me wild,—
When uncontroll'd my nature 's mild;
And oft the nymph, in dewy grot,
Seeks solace from my plaintive note;
O'er lovers' graves I waft a sigh,
And breathe the sound of sympathy.
'T is I who, from the trembling lyre,
Bring tones of love and soft desire;
'T is I, the spirit of the shell,
Who fill with notes the listening dell;
And, when the war-trump sounds alarms,
'T is I who summon men to arms.
To man a slave, though free as air,
I grind his corn, his food prepare;
Should he to foreign climes proceed,
He yokes me like the neighing steed,
And, by my quick but easy motion,
He traverses the stormy ocean.
His children, too, my presence court,
To give them toys and make them sport:
Without my aid, their kites would lie
As useless weights that ne'er could fly;
Their humming-tops would soundless spin,
Unless I breath'd a spell within.
The modest maid, without my power.
Would wither like her kindred flower:
Unless my cup of sweets she sips,
Where are the rubies of her lips?
Unless my glowing rouge she seeks,
Where are the roses of her cheeks?
What art, again, can strew her tresses
With half the grace my skill possesses?
Ev'n goddesses are represented
In draperies which I invented.
Sometimes, 't is true, I am so frail
As ruffian-like to raise your veil,
And thus to curious man reveal
The charms you modestly conceal.
Revenge the deed. Announce my name,
For now you know the powers I claim."

"It is extremely pretty," exclaimed Louisa.

"It is beautiful," said Tom; "but I should like to find out the riddle it contains. What can that be which grinds our corn, and carries our ships across the sea? Canvas? Yes; canvas clothes the sails of the windmill, and forms those of the ship."

"And therefore visits every clime, while, as long as the sails remain fixed, they are quite tractable and steady," added Louisa.

"It will not do, Louisa: it cannot be canvas, for the sail is never boisterous when it is controlled; but when let loose, it shivers in the wind and is very unruly, whereas it is said in the riddle, 'When uncontroll'd my nature 's mild,' which is quite the reverse. Let me see. Can it be string? My top could not hum without string."

"How can string prevent the modest maid from fading like a flower?" asked Louisa.

At this moment Miss Villiers whispered in Louisa's ear, who shortly afterwards exclaimed, "I have it, Tom, it is AIR."

The juvenile group now attentively perused the enigma, in order to discover whether its different parts would admit of such an interpretation.

"And, pray, my dear Mr. Goodenough," said Mrs Seymour, "what say you to these puzzles? Do you hold them in as much horror as you would so many puns?"

"By no means, my good madam. An enigma is a perfectly orthodox species of composition, and is, indeed, sanctioned by the highest authorities of antiquity. The most ancient riddle on record is to be found in the fourteenth chapter of the book of Judges, and we have also numerous riddles in profane writers of ancient date."

"Did you ever read that invented by Cleobulus?" inquired Mr. Seymour of the vicar.

"Pray be so kind as to relate it," said Tom.

Mr. Goodenough, in compliance with this request, proceeded as follows:

"There is a father with twice six sons; these sons have each thirty daughters, who are parti-coloured, having one cheek white, the other black. They never see each others' faces, nor live above twenty-four hours."

"A very strange and unsociable family," observed Louisa.

"I should never guess it," said Tom, "if I were to dedicate a year to it."

"You have, nevertheless, my boy, just pronounced the name of the said father, and that, too, after a single moment's consideration," replied the vicar.

"The name of the father! how? where?"

"It is a YEAR."

"A year!" exclaimed the astonished boy.

"A year!" echoed Louisa; "to be sure it is: I now see it all clearly. His 'twice six sons' are the twelve months; the 'thirty daughters' the days of each month; and, since one day must necessarily pass away before the next can arrive, they may be truly said never to see each other's faces."

"Admirably expounded," cried the vicar.

"And each day," added Tom, "is certainly 'parti-coloured,' as it is made up of light and darkness."

Mr. Seymour then announced his intention of proceeding next morning with the consideration of Sound, for producing which so many toys are contrived.

On the morning of the next day Mr. Seymour accordingly began his remarks to the juvenile party by saying that our sensations of sound are caused by a certain kind of impulses communicated from the air to the ear.

"Is it the air which produces sound?" said Louisa: "I thought it was always occasioned by the vibrations of solid bodies. I remember, when Tom struck the finger-glass, that you immediately silenced the sound by placing your hand upon it, and which you told us stopped the vibration of the glass, and so destroyed the sound."

"I am just now speaking of the more immediate cause, but on the occasion you mention it was the more remote cause I had in my mind. Sound is undoubtedly the result of certain motions or vibrations produced in sonorous bodies; but these vibrations are communicated to the air, and from thence to the ear, in a manner which I shall presently explain."

"Do you mean to say, papa, that if air were entirely excluded, bodies would be incapable of producing sound when struck?"

"Not exactly. Air is the usual conductor of sound, and unless some other medium be substituted, the removal of it would prevent a sonorous body from communicating any sensation to the ear. Liquids, however, are capable of conveying the vibratory motion to the organ of hearing, for sound can be heard under water. Solid bodies will also convey it, and in a much

more perfect and rapid manner; thus the slightest scratch with a pin upon one end of a long piece of timber will be distinctly heard on applying the ear to its opposite extremity. The tramping of a horse is to be perceived at a greater distance by listening with the ear in contact with the ground, than by attending to the sound conveyed through the air. Upon the same principle, if we place our ear against a long brick wall, and desire a person at a considerable distance to strike it *once* with a hammer, the blow will be heard *twice*, the first sound travelling along in the wall, the second through the air."

"I now understand," said Tom, "the principle of an instrument which Dr. Doseall employs for examining the pulsations of the heart. He places the end of a wooden tube upon the breast, and applying the other extremity to his ear, declares that the sounds thus conveyed to it enable him to form the most accurate opinion in cases of diseased chest."

"In the same manner," observed Mrs. Seymour, "that you may hear the boiling of the tea-kettle, by placing the end of the poker on the vessel, and applying your ear to the handle."

"I believe that with only the help of the poker and the tea-kettle, it has been found possible to carry on a conversation with a person almost or entirely deaf from certain derangements of the ear. He has only to place the end of the poker between his teeth and rest the other end on the edge of the empty kettle, into which the other person speaks."

"I should like to try to hear through my teeth," cried Tom.

"Nothing is easier than to convince yourself of the fact that sounds inaudible through the air may reach the auditory nerves through the solid parts of the head. Take this cedar pencil, and holding one end between your teeth, scratch gently with your nail on the other end; you will then distinctly hear a scraping noise, which ceases to be audible the moment you remove your teeth from the pencil."

Tom declared that this experiment was perfectly convincing as to the fact of the propagation of sounds through solids. But Mr. Seymour showed another mode of demonstrating this fact, which each of the party tried in turn. He obtained a piece of broad tape or strip of linen, and tying the middle of it round the handle of a poker, he supported the poker by pressing an end of the tape firmly against each ear, so as thus to close it. The poker, thus swinging freely, when allowed to strike against

the fender even so gently as scarcely to be heard in the ordinary way, was, he explained, thrown into vibrations which, carried by the tapes directly to the ears, produced an impression like the sound of a deep-toned cathedral bell, or other similar sonorous body.

"I do not exactly understand what you mean by a *sonorous* body. Will not every body produce a sound when struck?" asked Fanny.

"Those bodies are called *sonorous* which produce clear, distinct, regular, and durable sounds, such as a bell, a drum, musical strings, wind instruments, and so on."

"And upon what does this peculiar property depend?" inquired Tom.

"Before I answer that question, I must explain the supposed nature of those vibrations of the air upon which sound depends; you will then readily perceive why one species of matter should be better calculated than another for exciting them. It is generally believed that sound is conveyed through air by a succession of pulsations, which are not like any with which you are already familiar, and which you may have some difficulty in picturing to your mind, because you have probably never examined visible motions to which they may be accurately compared. Have you ever observed the effect produced on a field of wheat when the wind passes over it?"

"Oh, yes," said Tom, "it causes waves to pass across the field, and I have often watched them, and thought how like the waves of the sea they are."

"Tell me, now, what is the movement of the separate stalks which produces the appearance of waves?"

"Each stalk does nothing but bend down, and then rise up again when the breeze has passed, and, in fact, sways backwards and forwards, so," said Tom, waving his forearm like an inverted pendulum.

"That is quite right," said Mr. Seymour; "and in the movements of the ears of the wheat we may find some analogy to what takes place in the propagation of sound. In the first place, notice that the waves sweep across the field, but each ear of wheat only moves backwards and forwards on its stalk. Here is a diagram (Fig. 27) which will show this. And notice that if we take a file of the wheat-stalks in the direction of the advancing wave at any one instant of time, each successive stalk is in a

different phase of its motion: *b*, the next to an upright one, *a*, will be a little inclined; the next, *c*, will be bent a little more, and so until we reach one, *e*, which has arrived at the lowest position. Then, as we pass along the file, each succeeding one is more and more erect, until, going through the same gradations in inverse order, we reach another upright one, *i*, and then the

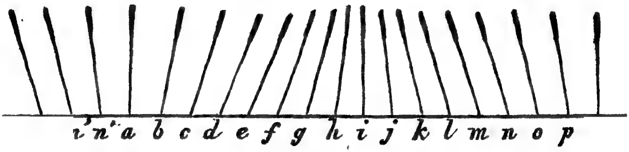


Fig. 27.

various phases of position will be repeated as before; but now by the stalks swinging beyond the vertical position, as at *j*, *k*, and *l*—*m* being a stalk at the limit of its inclination, and *n*, *o*, and *p* returning again towards the upright, as at *a'*. These are the positions at one instant of time; but now you must imagine all the stalks to be simultaneously swinging right and left alternately; at the instant represented in the diagram, the ears between *l'* and *e* are waving to the right; those between *e* and *m* are moving to left, and those between *m* and *a'* to right again."

"It is rather puzzling," said Tom.

"I am confident, however, that you will soon master it, and be able to picture these movements clearly in your mind. After that I must ask you to attend to the different distances between the ears which the movement produces, for it is there that the closest analogy lies to the movements of the particles of air which constitute sound. Examine the diagram and see how the phases of distance regularly succeed each other in the line, and you remember also that at every part of the line the various phases succeed each other from moment to moment. Thus, the places of greatest approximation and of greatest recession will move regularly along the line, at the rate the visible wave advances over the corn-field. Now consider the case of sound passing, let us say, through an iron rod, one end of which we may suppose to receive a blow from a hammer in the direction of its length. The rod must be pictured as made up of an immense number of extremely thin parallel transverse layers or

slices, and in the propagation of sound the movements of these will correspond with those of the ears in the wheat-field. The forces acting on the layers maintain them in the ordinary condition at a certain distance apart, but the blow of the hammer would set up a backwards and forwards swinging movement, communicated from layer to layer, not instantaneously, but progressively; and attended therefore by a regular advance of the places of greatest condensation, greatest separation, and every intermediate phase, with a speed which is the velocity of the sound along the iron bar."

"I think," said Tom, "I have read of the movements by which sounds are transmitted as being of the same kind as the waves in water."

"There are certain similarities in the two cases," replied Mr. Seymour; "but to say that sound-waves are of the same kind as those you observe on the surface of water is an erroneous, or at least misleading, statement. The similarity consists in the fact that the parts of the water and of the sound-conveying medium perform very limited movements, and that each particle passes in succession through a series of similar phases, not itself advancing in the direction of propagation, but in its oscillation causing the phases of movement to advance. There is a difference of great importance in the cases of waves in water and sound-waves, in the fact that in the former the particles of the water have a part of their motion transverse to the direction of the progress of the waves, while in the latter the movement is wholly a backwards and forwards one in the direction of the advance of the sound. The spreading out of the undulations from the point at which a stone is dropped into a quiet pool will, however, give you a notion of the spreading of a sound-undulation from a point of disturbance in the air, though the water-waves are visibly divergent in only the horizontal plane of the water's surface, whereas the sound-waves spread in all directions, and instead of forming circles about the original point, form ever-enlarging spheres, as the film of a soap-bubble does while it is being blown out. You will easily understand now that the original impulse, having its force spread out in ever-enlarging spheres, is weakened, just as the intensity of light diminishes as we remove from its source, and by the same law of the inverse square of the distance."

Louisa here asked at what speed sound travels.

"Its velocity is very different in different media," replied Mr. Seymour. "In some solids it travels at the rate of 17,000 feet per second, and in others at less than one-fourth of that speed; in water at about 4,700 feet per second. Its velocity in air is much less, for on a cold day it is only 1,090 feet per second, whereas on a hot day, such as this, it will travel at about 1,140 feet per second."

"What a curious thing," said Louisa, "that the mere warmth or coldness of the air should make any difference!"

"One of the lessons which I hope you will learn from our conversations is that in nature nothing stands apart."

"You promised," said Louisa, "when you were speaking about sound, that you would explain to us the cause of the echo in the valley, and tell us about other echoes."

"An echo is nothing more than a reflected sound. When the aërial vibrations strike against any obstacle of sufficient magnitude, they are reflected back to the ear, and produce a repetition of the sound, which will appear to proceed from the point whence they are reflected, so that the apparent direction of the voice becomes completely changed by an echo. A considerable extent of level wall will sometimes produce it in great perfection, for a smooth surface reflects sounds much better than a rough one; but the circumstance which, perhaps, contributes more than any other to the perfection of an echo is the form of the reflecting surface. A convex surface is a very bad reflector of sound; a flat one reflects very well; but a small degree of concavity is the form best adapted to the purpose."

"I believe," observed the vicar, "that fluid bodies will also, under certain circumstances, so reflect sound as to produce echoes."

"Undoubtedly: the surface of water, especially at the bottom of a well, and sometimes even clouds, will produce this effect."

"Do you mean to say, papa," asked Tom, "that sound is reflected from an obstacle to the ear in the same manner as my ball is reflected after striking the wall?"

"Certainly, supposing, of course, that your ball is perfectly elastic, and, in that case, you no doubt remember the direction it will follow."

"It will always make the angle of *reflection* equal to the angle of *incidence*," said Tom.

"Undoubtedly; and so it is with sound, since air, as you know,

is perfectly elastic. If, therefore, the vibrations fall perpendicularly on the obstacle, they are reflected back in the same line; if obliquely, the sound returns obliquely in the opposite direction, the angle of reflection being equal to that of incidence. You will, therefore, readily perceive that a person situated at an appropriate angle may hear an echo as it is returned from the reflecting surface without hearing the original sound which produced it."

"As a smooth and concave surface is capable of producing an echo, how does it happen that we so rarely meet with one in a room?" asked Louisa.

"Echoes, my dear, are, in fact, produced in every room by the reverberation of sound from its walls, but on account of the velocity with which it travels they are imperceptible in small chambers, because the impulse occupies no sensible period of time in moving from the mouth to the walls and in returning to the ear again, consequently the original sound and its echo become so blended and incorporated as to appear but one sound. As the dimensions of the apartment increase, the defect will increase with it; and in buildings for music or public speaking it is often highly inconvenient, and difficult of prevention. Breaking the surface, or rendering it uneven by mouldings and ornaments, or by draperies, appears to be the most effectual method of curing the evil."

"I perceive then, papa, that in order to produce a perfect echo, the person who speaks must be at a considerable distance from the obstacle that reflects the sound," said Louisa.

"It cannot be otherwise," replied her father; "and if you will only consider the rate at which sound travels, you will readily understand the necessity of such an arrangement. In order to produce a distinct echo of one syllable, or of a single sound, the reflecting obstacle must be at least 70 feet from the sound, so that it may have to pass through a distance of 70 feet to get to the reflector, and 70 more to return to the ear, making a total passage of 140 feet, which it will accomplish in about one-eighth of a second—a period of time so small, that, if it were diminished, it is evident the echo must be assimilated with the sound itself."

"But the echo in the valley," observed Louisa, "will repeat three or four syllables."

"Undoubtedly, if we make the experiment at a sufficient distance from the rocks which act as the reflector."

"It would appear, then, that the farther the reflecting object is off, the greater number of syllables will the echo repeat; and I should think that this fact might enable us to compute the distance of the reflector," said Louisa.

"In a moderate way of speaking, about three and a half syllables are pronounced in one second, or seven syllables in two seconds. When an echo, therefore, repeats seven syllables, we may infer that the reflecting object is 1,140 feet distant."

Louisa here remarked that she had heard of some very extraordinary echoes in different parts of the world, which repeat the same sound several times in succession.

"From the explanation which I have already given of the nature of echoes," said Mr. Seymour, "it will be easily conceived that a vast variety of effects may be produced by varying the form, the shape, the distance, and the number of reflecting surfaces; and hence we hear of various surprising echoes in different places. It is not difficult, for instance, to understand the nature of compound or tautological echoes, in which the exclamation of one *ha* will appear like a peal of laughter. Addison mentions an extraordinary instance of this kind near Milan, which will return the sound of a pistol fifty-six times."

"I have understood that the echoes on the Lakes of Killarney are of this multiplied description," said the vicar.

"They are particularly calculated to produce reflections of sound, from the height of the mountains and the expanse of water," replied Mr. Seymour, "which latter circumstance always assists the conveyance of reflected as well as direct sound. I believe that there is a certain spot on the shore of Ross Island where the sound of a bugle produces an echo which far exceeds any other to be met with amongst the lakes. The first echo is returned from the castle, the second from the ruined church of Aghadoe, the third from Mangerton, and afterwards innumerable reverberations are distinguished, which, like the fading brilliancy of an extremely multiplied reflection, are gradually lost by distance and repetition."

"There is an admirable echo," said the vicar, "behind my old college at Cambridge, and often have I, while walking on the road to Chesterton, on a calm evening, distinctly heard twelve repetitions of the voice. Lord Bacon, if I remember correctly, mentions an instance of sixteen in some ruined church near Paris."

"It was in the church of Pont-Charenton, on the Seine," replied Mr. Seymour, "in which place that great philosopher discovered the inability of an echo to return the letter S; for when he pronounced the word *Satan*, the echo replied *va-t-en*, which in French signifies *go away*, from which circumstance the Parisians concluded that some guardian spirit prevented the walls of the sacred edifice from pronouncing the name of *Satan*."

"And will not an echo repeat the letter S?" asked Louisa.

"Not always," answered her father: "the hissing or sibilant noise of the letter when at the commencement of a word is generally lost, unless the echo be extremely perfect."

Mr. Seymour then proceeded to explain to his young pupils the manner in which the reflection of sound produces its curious effect in the whispering gallery at St. Paul's Cathedral; and in order to render intelligible the manner in which sound is concentrated, and thereby magnified, in that hollow hemisphere, he produced a diagram, of which the annexed cut is a copy.

He explained it as follows:

"M shows the situation of the mouth of the speaker, and E that of the ear of the hearer. Now, since sound radiates in all directions, a part of it will proceed directly from M to E, while other rays of it will proceed from M to *u* and from M to *z*, &c.; but the ray that impinges upon *u* will be reflected to E, while that which first touches *z* will be reflected to *y*, and from thence to E; and so of all intermediate rays, which are omitted in the figure to avoid confusion. It is evident, therefore, that the sound at E will be much stronger than if it had proceeded immediately from M without the assistance of the dome; for in that case the rays at *z* and *u* would have proceeded in straight lines, and consequently could never have arrived at the point E."

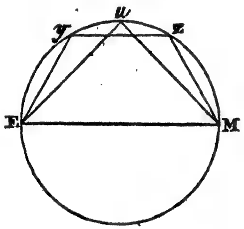


Fig. 28.

The vicar stated that there was also a whispering gallery in Gloucester Cathedral, where a narrow passage, 75 feet long, extends across the western end of the choir, forming five sides of an octagon, and here the voice of a person whispering gently at one side of the choir is carried by reflection to the ear of a person at the other side.

"The perfect reflection of sound," said Mr. Seymour, "by certain forms of walls and roofs, is well illustrated by a story which is told of the cathedral of Girgenti, in Sicily, where the gentlest whisper from a particular spot behind the high altar is distinctly heard by a person near the western door, at a distance of 250 feet. The ecclesiastics had unwittingly placed the confessional in one focus of the sound-reflecting surfaces, and by accident the other focus was discovered by a person who amused himself by listening to secrets intended for the priest alone."

Mr. Seymour now removed a large shell which decorated the mantelshelf, and desired Tom to place it to his ear.

"I hear a noise which appears to me to resemble that of the sea," cried Tom.

"Ay," said the vicar, "and there is a popular belief that it is the murmur of the waves which the shell actually sends forth, betraying, as it were, its marine origin; and this is finely alluded to by Wordsworth, who says:

"'I have seen
A curious child, who dwelt upon a tract
Of inland ground, applying to his ear
The convolutions of a smooth-lipped shell;
To which in silence hushed, his very soul
Listened intensely; and his countenance soon
Brightened with joy; for murmurings from within
Were heard—sonorous cadences! whereby,
To his belief, the monitor expressed
Mysterious union with its native sea.'"

"And what produces the sound?" inquired Louisa.

"The interior of the shell merely concentrates, and thus multiplies, the sounds around us, so as to render them audible. A goblet applied to the ear will be found to produce the same effect," replied her father.

"I suppose it is upon the same principle that the speaking trumpet is made to convey sound to a distance," remarked Louisa.

"Since sound radiates in all directions, it follows that if such radiation be prevented by confining it in tubes, it may be carried to a great distance with very little diminution of its effect, and hence the use and application of those gutta-percha, or tin speaking-pipes, which are now commonly used for conveying intelligence from one part of a house to another. The trumpets used by deaf persons act on the same principle; but as the voice

enters the trumpet at the large instead of the small end of the instrument, it is not so much confined, nor is the sound so much increased."

"I believe," said the vicar, "that the experiment exhibited many years since in London, under the title of the *Invisible Girl*, and which excited such general curiosity, was discovered to depend upon an arragement of this kind."

Mr. Seymour thereupon proceeded, by the aid of sketches like those in Figs. 29 and 30, to explain to the children the way in which this famous illusion was produced.

"The visible portion of the mechanism consisted," he said, "of a wooden frame, not very unlike a bedstead, having four

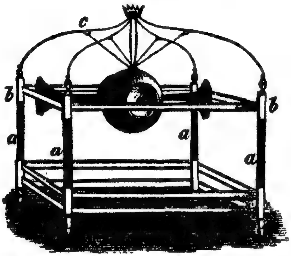


Fig. 29.

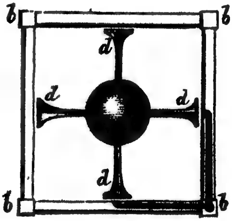


Fig. 30.

upright posts, *a a a a*, and a cross-rail at top and bottom to strengthen them. The frame thus constructed stood upon a low table, and from the top of each of the four pillars sprang four bent brass wires, which converged to the point *c*. From these wires a hollow copper globe, about one foot in diameter, was suspended by ribbons, so as to cut off all possible communication with the frame. The globe was supposed to contain the invisible being, as the voice apparently proceeded from the interior of it; and for this purpose it was equipped with the mouths of four trumpets, placed round in a horizontal direction, and at right angles to each other, as shown in the annexed plan (Fig. 30), in which the globe is represented in the centre; *d d d d* are the trumpets, and *b b b b* the frame surrounding them, at the distance of about half an inch from their mouths."

He told them that the mechanism owed its effects to the combined operation of two principles with which they were

already acquainted: the concentration and conveyance of sound by means of a speaking-pipe, and its reflection from an appropriate surface, so as to change its apparent direction by producing an artificial echo. He then showed how a pipe which was concealed in one of the legs of the frame conveyed to the mouth of the trumpet, and thence reflected to the ear of the observer, the voice of a female confederate stationed in an adjoining room. By means of the annexed section we shall hope to render this subject as intelligible to our readers as did Mr. Seymour to his little pupils.

b b represent two of the legs of the frame, one of which, as

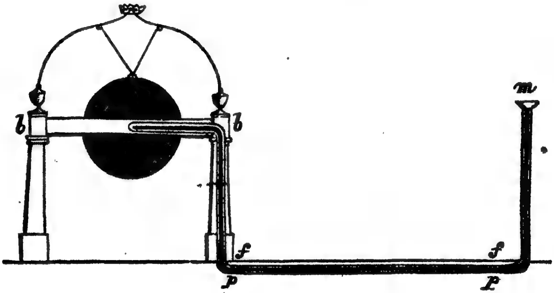


Fig. 31.

well as half the rail, is made into a tube, the end of which opens immediately opposite to the centre of the trumpet. This hole is very small, and concealed by mouldings; the other end communicates by a tin pipe, *p p*, which passes, in a concealed manner, along the floor of the room into an adjoining closet, where the confederate is concealed. It is evident that any sound directed into the mouth of the trumpet will be immediately reflected back to the orifice of the tube, and distinctly heard by a person who places his ear to the mouth of the funnel *m;* while the answer returned by him, travelling along the tin tube, *p p*, will issue from its concealed orifice, and, striking upon the concave surface of the trumpet, be returned to the ear as an echo, and thus appear as if it had proceeded from the interior of the ball.

The vicar observed that "this deception of the Invisible Girl, which had formerly created so much interest, was little more

7—2

than the revival of the old and well-known mechanism of the *speaking head*, which consisted of a tube from the mouth of a bust leading to a confederate in an adjoining room, and of another tube to the same place, ending in the ear of the figure, by the latter of which a sound whispered in the ear of the bust was immediately carried to the confederate, who instantly returned an answer by the other tube ending in the mouth of the figure, which therefore appeared to utter it. The Invisible Girl," continued the vicar, "evidently only differs from that contrivance in this single circumstance, that an artificial echo is produced by means of the trumpet, and thus the sound no longer appears to proceed in its original direction."

"Your remark is perfectly correct, my dear vicar," said Mr. Seymour; "and you no doubt remember that Albertus Magnus, Roger Bacon, and others, were regarded by their contemporaries as magicians because they constructed these speaking heads. Yet the simple principle on which they produced their apparently magical effects is at the present day now applied in every large warehouse or office to the speaking-tubes that pass between the different apartments."

The evening of the day on which the conversation just related took place was one of those which so frequently occur in August, when the sultry heat is succeeded by refreshing coolness. And as Laura Villiers possessed a quick sensibility for the beauties of nature, and an imagination keenly alive to the poetic aspects of landscape, it was quite in accordance with her disposition that she should quit the drawing-room as she did, to enjoy alone the pensive quiet which at that hour reigned over the scene. She stepped out unperceived in the twilight, and sauntered along the winding paths of the shrubbery. The moon, which had just risen, was tipping the summits of the trees with her silvery beams, leaving the mass of the foliage in deeper shade, as Laura, after having traversed several sinuous avenues, found herself in one of those sequestered glades we have before described, and here she sat down on a rustic bench at the foot of an aged oak. The time was favourable to the indulgence of that species of vague reverie, which for some natures has so powerful a charm as to take a high rank in the scale of pleasures. Be it understood, however, that in the mental constitution of our heroine there was too large a share of that healthy activity which properly occupies itself with the external world to permit

her habitually to resign herself to dreamy musings; but perhaps there might have been in the recent events of her personal history something which on this occasion disposed her to give the rein to fancy. Certain it is that while sitting there, with her ear soothed by the gentle murmur of the little stream in the valley, recollections of the past and anticipations of the future mingled indefinitely in the current of her thoughts, with a half-conscious contemplation of the scene present to her eyes.

But now the moon, suddenly peering down the shady avenue, threw its rays upon one of the statues already mentioned as giving to these groves an air of classic solemnity. It was a figure of Time, which, concealed hitherto in the obscurity of the shadow, seemed at this moment to emerge from the gloom. When the mind is occupied by some particular train of ideas, the simplest occurrence—the fall of a leaf to the ground, or the wafting of the fragrance of a violet on the breeze—may attract unwonted attention if it happen to accord with the current of our thoughts.

Laura rose from her seat and approached the figure, whose countenance, as the direct beams of the moon fell upon it, seemed, as she thought, to wear a placid smile. "There," mused our heroine, "there stands Time, at once the friend and the foe of mortals. Oh that he could unfold the mystic volume of the future, that I might read therein what fate awaits me!" As she thus mentally shaped her wish into words, her eye glanced from the face of the figure to the hour-glass in its hand. That emblem was entwined with roses—the work of a passing caprice which Louisa Seymour had, unknown to her friend, that day indulged. "Were I susceptible of superstitious impressions," thought Laura, "I should receive this as an omen of happy prospects." But, smiling at her own fancies, she turned aside into a path which she knew led to the valley, where she longed to view the effects of the moonlight. Some of our readers may perhaps think that this young lady must have possessed an exceptional amount of bravery thus to ramble alone in these secluded paths; but it must be remembered that not only was Laura a girl of spirit, but that she was now possessed by a sentiment which in the female breast often imparts all the power of courage—the feeling, we mean, of curiosity. Besides, it must be confessed that when she had nearly reached the valley, as a passing cloud suddenly intercepted the moon's light, she

did for a moment pause, and hesitate between the accomplishment of her project and an immediate return to the mansion. It was, however, but for an instant; for, ashamed of her timidity, she resolutely continued her walk, and in a few moments arrived at the spot where the impending rocks on the other side of the stream rose abruptly from its banks.

Not a sound disturbed the stillness save the subdued murmur of the water, and Laura viewed with delight the glitter of the little ripples in the moonbeams. But now her courage was to be more severely tried, for she thought she heard her own name strangely but softly pronounced. Could it be a mere illusion of her fancy? She listened again very attentively, and felt sure she heard the word "Laura" distinctly repeated. Startled for one instant by this unexpected challenge, she perceived in the next that the sound seemed to proceed from the opposite rocks, and it flashed upon her mind that she was in the presence of the echo of which she had heard that afternoon. But where was the person who was thus making the quiet dell vocal with the name of Laura? All the party at the Lodge she had left in the drawing-room, and the path she had followed was the only one by which the valley could be entered. The sound was, however, not repeated; and our heroine retired from the spot, not in trepidation, but in perplexity—resolving to return to the Lodge, and at supper relate her adventure to Mr. Seymour, and hear his explanation of the mysterious voice.

CHAPTER VIII.

O Music! thy celestial claim
Is still resistless, still the same!
And faithful as the mighty sea
To the pale star that o'er its realm presides,
The spell-bound tides
Of human passion rise and fall for thee!

WHEN Laura had related her adventure, Mr. Seymour smilingly told her it must have been the solitary spirit of the dell which pronounced her name.

"You are not the first," said he, "whom the gambols of our rural sprite have startled in the shades of evening. Though it is almost a pity to divest your adventure of its romantic veil of mystery, I am bound to tell you that the voice you heard was but an echo."

"Indeed, Mr. Seymour," replied Miss Villiers, "I cannot see how the sound could have been an echo, for I never spoke; and I am sure there was no one near me."

"But Mrs. Seymour called your name at the gate of the orchard; and to-morrow I will convince you that, distant as the valley is from that point, the sound reaches the semicircle of rocks, especially in certain calm conditions of the atmosphere; and by the peculiar amphitheatre-like configuration of the rocks, sounds, otherwise too faint to be heard, are concentrated by reflection, and become audible near the part of the valley in which you were standing."

Miss Villiers was now perfectly satisfied with this explanation, and remarked that her adventure would certainly have the effect of impressing upon her memory all she that day heard about sound and echoes; and now that the mysterious voice had been so satisfactorily accounted for, she really was surprised that she had not at the time recalled to mind the instances which had been mentioned of the concentration of sounds by reflecting surfaces.

The present which Mr. Seymour next day gave to Tom was one of those small musical boxes, which, though not much larger than an ordinary snuff-box, perform several airs by the action of the clockwork they contain. The mechanism of the toy was explained, and the difference of the sound when the box is placed on the table or on a cushion was readily noticed.

"Now, I see," said Tom, "that the sonorous body in this instrument is the steel plate with its comb-like teeth, which are of a length gradually ranging from one end of the barrel to the other. But why is it that each of these emits a sound as it is released from the projecting teeth in the barrel?"

"I must tell you," replied Mr. Seymour, "that all sonorous bodies are such by reason of their elasticity. A body will not emit a musical note unless its parts are capable of being thrown into a state of very rapid vibratory movement, and this kind of movement is possible only in elastic bodies. A ball of damp clay, which does not possess this property, will produce no other sound, when struck, but that which arises from the condensation of the small portion of air between the clay and the hammer which strikes it. A hollow ball of brass will produce more sound, because it is elastic; but still very little effect will arise from this, since a ball is the worst shape for admitting of vibration, on account of its forming an arch or dome in every direction, so that one part stiffens and sustains the other; but if such a ball be divided, and the edge of one-half of it struck, a loud,

clear, and distinct tone will be produced, because a hemisphere will admit of the exertion of elasticity, or of momentary change of figure, which is conducive to the perfection of sound; and accordingly the bells used for clocks and for musical purposes have generally such a figure."

"I see clearly," said Louisa, "that it is the vibration of a sonorous body that communicates the necessary motions to the air, and I suppose that a body vibrates in proportion to its elasticity."

"Certainly it does, and we shall have occasion to recur to this subject presently; but I wish to show you by help of this musical box how perfectly solid bodies can conduct sounds. Here, you see, I have two boxes, which are, in fact, merely two empty cigar-boxes. In the bottom of one of these I have made a hole of about ¼ inch diameter, through which I can pass this slender wooden rod, which is about three feet long. We will now wind up the box and set its music going, and now I am placing it in the middle of the box, packed all round with cotton wool, except only where the end of the rod rests upon it. I fasten up the bottom of the box, and I place it upon the table with the rod rising upright from it."

"Why, papa," said Louisa, "the box has stopped."

"No, my dear, if you will listen attentively you will hear it, but very faintly. The sound is cut off by the cotton wool, which, under these circumstances, hardly transmits the vibrations at all. The wooden rod, on the other hand, is transmitting them freely, and along this rod every note of the instrument is flowing in invisible oscillations of its particles, which communicate the impulses to the particles of the air. But as the extent of the surface of the rod is small, the motion is communicated to comparatively few of the air particles. Hence the extreme faintness of the sound. But observe the difference when I place this second cigar-box, the lid of which I remove altogether, upon the end of the stick."

"I declare," cried Louisa, "the music is now quite as loud as if the instrument were on the empty box, and the sound seems now to come from there."

"Yes, and the reason is that the vibrations are transmitted from the end of the rod to the large surface, and now so many air particles are struck, that the tune is, as you say, about as loud as if this empty box itself supported the instrument. Now

I remove the box which acts as a sounding-board, and the music is again inaudible; I touch the rod again, and once more you hear the air."

The children were immensely delighted by this pleasing proof of the conduction of sound by solid bodies, and each in turn amused himself or herself by alternately putting the extemporized sounding-board on the wooden rod, and lifting it off; thus at will sending to the ear, or suppressing in silence, the harmony which the industrious little musical box was continuously pouring forth.

Mr. Seymour then informed the young people that he had once witnessed this experiment performed on a large scale, at a public institution in London, where the exhibitor appeared on the stage with nothing but four harps. Presently from one of the harps the notes of a pianoforte were heard to issue, from a second the clear tones of a clarionet, the third emitted the wailing strain of a violin, while the grave harmony of the violoncello poured from the fourth.

"Did the exhibitor touch the strings of the harps?" asked Louisa.

"Not at all: the sounds issued from the sounding-boards of these instruments, and the effect was curious, from the absence of any visible cause for the music, and from the unwonted nature of the sounds which seemed to come from the harps. But I can show you a picture by which you may see at once how the *telephonic concert*, as it was termed, was managed. Here you see the harps, and the audience seated round them, in a room above an intermediate hall, below which are stationed four performers. To each instrument a slender rod is attached, rising through the hall, where the sounds are inaudible, to reach the upper room, where, passing through the floor, they come into contact with the sounding-boards of the harps."

"As I now understand how sound is produced and carried to a distance, I should much like to learn the cause of different tones," said Louisa.

"Know then, in the first place, that all sounds you hear are made up of a number of rapidly recurring impulses. If these impulses succeed each other irregularly, the result is a noise; if, on the other hand, they follow each other with a certain regularity, a musical note is produced. Now, the pitch of the note depends on the rapidity of the impulses sent to the ear; that is, upon the

Fig. 32.

number of vibrations per second which is made by the sounding body. It is easy to notice the fact that pitch depends upon the rapidity with which the impulses succeed each other. As I pass this card round the milled edge of this coin, you hear, when the movement is slow, the distinct impulses; but when the motion is quicker, these give place to a noise in which you may recognize a grave note; and when I make the movement yet more rapidly, you will distinguish a rise in the pitch of the sound. Now, the reason the shorter teeth of the steel plate in your musical box yield the higher notes is because the vibrations of a rod (like the oscillations of a pendulum) are quicker the shorter the rod is."

"The vibrations," said Louisa, "are, I suppose, much too rapid to be seen?"

"You will remember, from our experience with the thaumatrope, that the impressions made on the eye remain for a certain time, and for that reason, when a body oscillates so as to occupy the same position oftener than eight times in a second, we receive a permament impression from it. Now, when I stretch this piece of cord very tightly by tying it to one of the legs of the table, and passing it round the other, you will notice that when I pluck the cord in the middle—so—it gives out a musical note, just as the string of the harp does, but fainter, from the absence of a sounding-board. You will notice that the string produces on the eye, while vibrating, the effect of a spindle-shaped body, with a semi-transparent gauzy appearance in the central parts. You hear, when I tighten the string at the same time that I pluck, how the note of the twang rises."

"Yes," said Louisa, "I know that the tighter the cord or wire, the higher is the note; for I have seen the pianoforte tuner tighten or release the wires, according as the note required to be made sharper or flatter. And I have also noticed in the harp and piano that the cords and wires which produce the highest notes are the shortest."

"It has been found," replied Mr. Seymour, "that with the same tension in the same wire or cord, a piece of half the length will give a note exactly an octave higher—that is, it will perform just double the number of vibrations as a cord of twice its own length."

"This fact was discovered," observed the vicar, "by Pythagoras more than five centuries before the Christian era. He stretched a string, and having divided it into three equal lengths,

he fixed it firmly at one of the points of division, so that it thus virtually became two strings similar in every respect, except that one was twice the length of the other. He then found, on sounding the two sections at the same time, that a perfect concord was produced. He also found, when he divided his string in other proportions, that concordant notes were yielded only when the lengths of the sounding parts had some very simple ratio to each other, as, for example, 2 to 3, or 3 to 4."

"I am thankful to the vicar for reminding us of this," said Mr. Seymour, "for this discovery of Pythagoras had no little influence in ancient philosophy, as it probably led him to the axiom that the universe is governed by numbers and harmony; and Pythagoras, who was the first in Europe to teach that the planets revolve about the sun, also supposed that their distances therefrom were in the same ratio that express the relations of the seven notes of the musical scale. Hence, perhaps, the notion of the music of the spheres, which was imagined to be produced by the rotation of the crystalline spheres that carried the heavenly bodies, and to be so loud and sweet that by mortal ears it was unappreciable, and therefore unheard by men. The real physical cause of the concordance of certain musical notes has only quite lately been made out."

"Do tell us, papa, what it is!" cried Louisa.

"The subject is not one we can enter into, but I may just indicate to you the direction in which its explanation is to be found. Tell me what is the higher note which gives the most perfect harmony with the C near the middle of the keyboard of the piano?"

"The C of the next octave."

"And what other concords are there in the octave—I mean, what notes struck with the C would produce the most pleasing effect on the ear?"

"There is G, which is the *fifth*, and E, which is the *third* note higher."

"Now, it is known that the note C of which I have been speaking corresponds with a rate of vibration of 528 per second."

"I cannot understand how movements so extremely rapid can possibly be counted," said Louisa.

"The principle is simple," replied Mr. Seymour. "Suppose that I have a wheel with 132 teeth, and I press a spring against

the wheel in such a manner that a sound is made as each tooth passes; then, as I have already said, when the separate impulses occur with a certain rapidity, which is about twenty in a second, a low musical note is heard; and if the velocity of the wheel be increased, the note will rise. It is quite easy to attach to such a wheel a train which shall register the number of revolutions per minute; and when the wheel is turned so that it makes four revolutions per second, the note will be in unison with the note of the pianoforte; if the rate be quickened to eight revolutions, when 1,056 teeth would pass under the spring in a second, the note would be the octave higher. But here I will show a table of the number of vibrations corresponding with each note of the octave.* Look, now, at the number of vibrations in C and G, and observe that they have the simple ratio to each other of 2 : 3; while those of C and E are to each other as 4 : 5; and in every case in which a fundamental note is compared with its higher third, fifth, and octave, the numbers of vibrations are found to have these simple ratios to each other, 4 : 5 : 6 : 8."

"And I suppose," said Louisa, "that if the numbers of vibrations do not *quite* answer to these proportions, the harmony would not be *quite* perfect, but would be better the nearer the numbers agreed."

"On the contrary," replied Mr. Seymour, "the discord is most grating and harsh when the numbers differ but little, and the combinations which give the most inharmonious effects are precisely those which nearly but not quite agree with the proportions I have stated. Now, from these and other facts, by a long course of beautiful experiments and clear reasonings, a living man of science has succeeded in giving a satisfactory theory of the physical causes of harmony, but you are not yet in a condition to understand such investigations."

Louisa here wished to know how it was that the same note was always yielded by the wires of the pianoforte, whether the key of the instrument were struck quickly or slowly.

"To understand that fact," replied her father, "you must know that the wire does not alter the period of its vibration with the force of the blow. The only effect is to impart a greater swing to the wire, it is made to traverse a greater space, and as by the laws of all vibrating bodies it performs the vibration

* NOTE A.—Musical Pitch.

always in the same time, its velocity is greater; hence the loudness of the note is increased, but the pitch remains the same."

"There is," said Louisa, "another circumstance which I do not think your theory explains. When the same note is sounded by a violin, a flute, a concertina, and other instruments, one recognizes the fact of their pitch being the same, while the tones themselves are quite distinct and different, each having a quality of its own."

"The reason is, that no sounding body sends out a single set of regular undulations. A vibrating wire, for example, vibrates not only as a whole, but divides itself into shorter vibrating segments, each of which contributes to the actual sound. It is the mixture of these (*overtones*, as they are called) with the fundamental tone, which gives the character to the sound of different musical instruments. It is true that the overtones are rarely noticed, but the reason is that an attentive ear is required to pick them out of the general mass of sound, and it seldom or ever happens that attention is directed to them, as even a musician is not required to analyse the sound of his instrument,—the general effect upon the ear suffices for him. The overtones may be very numerous, and may vary greatly in relative intensities, and thus the variety of qualities in sounds may be accounted for. For instance, the same voice singing in the same note the different vowels, and different voices singing the same vowel in the same note, all produce different effects, which are easily explained by the various mixtures of overtones with the fundamental note. You will, perhaps, more easily understand the operation of such mixtures and superposition of vibrations by the analogical case of colours. If every note emitted by the voice or by musical instruments was simple, and gave rise only to one set of sound-undulations, the only possible difference in sounds would be in pitch and loudness, and a piece of music would in such a case be similar to a painting which would be produced by an artist who was compelled to spread on his canvas no other tints than the pure unmixed colours of blue, red, yellow, green, &c. How much we should miss the varied and broken hues which now charm the eye!"

"Upon my word, Mr. Seymour," cried Mr. Goodenough, "you are getting out of your depth; pray let us take leave of this part of the subject, for I am quite sure that my young friends have already received more than they can carry away."

"I submit, my good sir," said Mr. Seymour; "but I should like to say a few words upon the different kinds of musical instruments, and you will, perhaps, kindly give us your opinion as to the antiquity of the various forms of these. It appears to me that musical instruments may be classed under three heads —*stringed* instruments, such as the harp, violin, &c.; *wind* instruments, as the flute and trumpet; and instruments of *percussion*, as the tabor and drum."

"And what kind is considered the most ancient?" asked Louisa.

"*Wind* instruments, most unquestionably," cried Mr. Goodenough. "Diodorus ascribed their invention to the accidental notice of the whistling of the wind in the reeds on the banks of the Nile, and the poet Lucretius maintained a similar opinion:

> "'Et Zephyri cava per calamorum sibila primum,
> Agrestes docuere cavas inflare cicutas.'"

"I really, my dear sir, cannot see any good reason for giving this preference, in point of antiquity, to wind instruments," said Mr. Seymour. "The lyre or harp is, surely, as ancient as any instrument on record. The mythologist ascribes the idea of producing sound by the vibration of a string to Apollo, which is said to have suggested itself to him on his hearing the twang of the bow of his sister Diana. With respect to instruments of percussion, it may be reasonably supposed that the sonorous ringing of hollow bodies, when struck, must have very soon suggested their invention to mankind; but I really consider any research into a question of such obscurity as uninteresting as it must be hopeless: let us rather devote our attention to the philosophy of these instruments. I have stated that they may be referred to three principal classes; but I must, at the same time, observe that, in some cases, the vibrations of solid bodies are made to co-operate with those of a given portion of air; for example, trumpets and various horns may be said to be mixed wind instruments, since their sound is produced by the joint vibrations of the air and a solid body; and in certain stringed instruments, as in the violin, the immediate effect of the strings is increased by means of a sounding-board, which acts more powerfully on the air than the strings could do alone."

"I apprehend that this mixture must obtain more or less in all instruments," said the vicar.

"Not in all. The flute, flageolet, humming-top, and the cavity of the mouth in whistling may be considered as simple wind instruments, in which the quality of the sound is alone determined by the vibrations of the air. I have already explained the manner in which the oscillations of a string excite aërial undulations, and thus produce sound, and you have seen that the nature of these sounds is determined by the length and thickness of such strings. The theory equally applies to wind instruments, in which case a column of air corresponds with the string, the volume and length of which determines the sound. In the harp the strings are constructed of different lengths and dimensions; and so, in the *Syrinx*, or *Pan's pipes*, is the volume of air adjusted to the respective notes by the size and length of the reeds; but in the violin the lengths of the strings are altered at pleasure by pressing them down on the finger-board; and, in like manner, the effective length of the flute is changed by the opening or shutting the holes made at proper distances in them, the opening of a hole at any part being the same in effect as if the pipe were cut off a little beyond it."

Mr. Seymour and the vicar then entered into a long and inflated antiquarian discussion, with which it is not our intention to swell our history, or to exhaust the patience of the reader. We shall, however, by permission, collect from the mass some of the more interesting facts, and present them in as condensed a form as may be consistent with perspicuity. In speaking of the *Jew's harp*, a little instrument with which every schoolboy is well acquainted, the vicar stated that its origin was lost in the long lapse of time, but that it was in very common use throughout Europe, and more especially in the Netherlands and the Tyrol, where it was the delight of the peasants and their families. He also said that it was known in Asia, and that the Greeks of Smyrna called it, in imitation of its sound, *biambo*. Mr. Seymour described its construction and the theory of its action. It is composed of two parts, the *body* and the *tongue:* the former has some resemblance to the handle of a certain kind of corkscrew, the latter consists of a little strip of steel, joined to the upper part of the body, and bent at its extremity, so that the fingers may touch it more readily. This tongue, or elastic plate, produces, in itself, only a sound which serves as a drone, although it appears to act like the motion of a bow of a violin in exciting other sounds, by breaking the current of air from the mouth, the

acuteness or gravity of which will be determined by the pressure of the lips and the magnitude of the cavity of the mouth.

After this conversation it was determined that the party should adjourn to the drawing-room, where it was expected that Miss Villiers, who was an excellent performer, would furnish some practical illustrations of the subject on the pianoforte, which she most cheerfully undertook to do. In the course of conversation Mr. Goodenough, with his usual veneration for antiquity, maintained the superiority of the music of the ancients over that of modern times.

"It is evident," he said, "that the art, as practised in ancient times, must have had great capacity for exciting pleasurable feelings; for not only the poets, but the historians and philosophers of the best ages of Greece and Rome, are as diffuse in its praises, as of those arts concerning which sufficient remains have descended to evince the truth of their panegyrics. What modern strains can produce the effects which followed the performance of Timotheus, the director of the music of Alexander the Great? The story has been related in immortal numbers by our own Dryden, and there can, in my opinion, be no doubt that, to quote Dryden's lines:

> "'Thus long ago,
> Ere heaving bellows learned to blow,
> While organs yet were mute,
> Timotheus, to his breathing flute,
> And sounding lyre,
> Could swell the soul to rage, or kindle soft desire.'"

"I confess, Mr. Goodenough," said Miss Villiers, "that I have always been inclined to regard ancient music as the mere vehicle of poetry, and to attribute to the power of the latter that influence which you appear to refer exclusively to the former."

"I am willing to admit," replied the vicar, "that, in the ancient theatre, music always accompanied her sister art, assisting, animating, and supporting her; but does not this rather prove that poetry in itself was insufficient to produce its effects without the aid of music? I fear, however, that music has degenerated from its ancient grandeur and power, for it certainly has now little effect on the emotions and sentiments of even the cultivated—perhaps I should have said of *at least* the cultivated—portion of society. If any one should be inclined to deny this my position, let him attend a modern party in London. I

have seen, my dear Miss Villiers, a party of a dozen persons *tête-à-tête*, and as many solitary individuals, sitting like automatons, not one of them being moved by the concord of sweet sounds with which some lady had been endeavouring to delight them. Had Timotheus appeared amongst them!—eh, Miss Villiers? I think I see the party at the whist-table as his lyre successively changed from the Lydian to the Phrygian mode. I must, however, in justice state that I once did see a lady at a whist-table lay down her cards in an apparent state of ecstacy as a chorus of Handel suddenly burst upon her ear, although she held three honours."

"And what chorus could that have been?" said Mr. Seymour; "surely it was '*Blest be the hand*'? But, joking apart, you appear to have satisfied your mind upon a point which all the learning of Europe has left in a state of doubt and perplexity."

"I have merely delivered an opinion, sir; you, perhaps, will favour us with your judgment."

"The subject under discussion, my good sir, is one upon which no person can ever deliver a judgment."

"And pray, Mr. Seymour, why not?"

"For this plain reason, that it is not possible we can *hear* both sides."

"Psha! will you never cease to sully the pure stream of inquiry with the dregs of ridicule?"

"Well, then, to be serious: I certainly do not believe that the ancients were better skilled than ourselves in music, and I am inclined to think that there are as many modern as ancient stories in proof of the influence of harmony over our feelings; but no one will deny that music is capable of producing extraordinary effects. Let us only recollect our own sensations on hearing a majestic or warlike piece of music, or a tender and pathetic air sung or played with expression. Who does not feel that the latter tends as much to melt the soul and dispose it to pleasure as the former to animate and exalt it? There is a celebrated Swiss air, which, I have no doubt, Miss Villiers will presently play to us, called the '*Ranz des Vaches*,' and which had such an extraordinary effect on the Swiss troops in the French service that they always fell into a deep melancholy whenever they heard it. Louis XIV., therefore, forbade it ever to be played in France, under the pain of a severe penalty. We

are also told of a Scotch air, '*Lochaber no more*,' which has a similar effect on the natives of Scotland."

"I think," said Miss Villiers, "that no one will deny the charm which the simple music of the ancients must have exercised over the hearer, although he may attribute much of the effect to the poetry, of which it may certainly be said to have been the vehicle. I concur with you, Mr. Goodenough, in thinking that, owing to the intricate combinations of modern harmony, astonishment at the execution of the artist too frequently interferes with the influence of the musical tones upon our feelings."

A somewhat novel musical pastime was now proposed by Mr. Seymour. He suggested that Louisa should withdraw for a few minutes from the room, while the party agreed upon some actions which she was to be led to perform with no other directions than Miss Villiers, stationed at the piano, could give her by playing the instrument. Not a word or a gesture was to escape from any one present. Accordingly, when the door was closed upon Louisa, it was agreed in a whispered consultation that she should first be required to take a rose out of the vase on the table and smell it; that she should then be directed to play the harp; and that finally she should be requested to lead Fanny out of the room.

Miss Villiers, first striking off an extemporized fantasia, summoned Louisa to enter by expressively introducing the air of "See the conquering hero comes;" then tastefully but significantly passing to other melodies with which—from a glance at the contents of Louisa's books of ballad music—she knew the latter to be acquainted, she played "How sweet are the flowers that grow," which at once sent Louisa to the vase of flowers; and at the first bars of the immediately following air, "Ask if yon damask rose be sweet," she seized the flower and began to inhale its delicious perfume. To the strain of "Gently touch the warbling lyre," and to that of Dibdin's song, "Say, Fanny, wilt thou go with me?" Louisa responded by performing the very actions agreed upon. The complete success of this musical diversion gave no little delight to the whole party.

CHAPTER IX.

**Plato denied the world can be
Governed without geometry.**

FROM incidental passages in the foregoing pages, it may perhaps have been truly inferred that the intellectual attainments of Miss Villiers were quite exceptional. But, in point of fact, her mental superiority did not lie in the possession of a great store of knowledge, obtained by arduous and continuous study; rather did it consist in the full and symmetrical culture which all her faculties had received. She was not a prodigy of learning; on the contrary, we can assure our readers that her bright eyes had never lost a ray of their lustre by the student's habit of poring over books beneath the midnight lamp, nor had her shoulders contracted even the suspicion of a stoop by any exclusive devotion to the printed page. Though she knew, and knew well, many things that are not usually com-

prised in a girl's education, that which more particularly distinguished her understanding was its capacity for growth, and the vitality by which it was ever assimilating new material to build up into ever-enlarging conceptions of truth and beauty.

By the untimely decease of her mother, Laura had been, while yet a child, left to her father's care, as a precious legacy, and the only offspring of a tender union, dissolved, alas! too soon. Laura's father was a physician, and he was moreover a man of high general culture and rare enlightenment. As the child became the object of his daily solicitude, he directed her training and education with unremitting attention, keeping constantly in view, as the object to be aimed at, the most complete and harmonious development of all her powers both of mind and body. The result well rewarded the fond parent's forethought and sagacity.

Perhaps it followed from her father's profession, and the constancy with which he carried out certain scientific views, that on the physical side Laura had received a training which had not only given her a vigorous and healthy frame, but had conferred on all her movements that easy and unstudied grace which is so powerful a charm even in the absence of regular beauty of form or feature. Still better than even grace of action was the everlasting and overflowing good humour which is the usual companion of such thorough healthiness as our heroine possessed. In manner Laura was modest, unobtrusive, and unaffected; but her disposition was not shrinking and dependent, for she had a fair measure of self-reliance. She was gifted with a ready wit, and in any extemporized piece of "admirable fooling," she would readily take a part, and sustain an assumed character with great liveliness. She could on occasion give a smart repartee; but never was there any ill-nature in her fun, nor did it ever take the form of insincerity, which is practised by those of the sex whose claim to be witty rests on nothing better than a trick of holding up to derision the weaknesses of each absent friend in turn.

If, instead of an artless tale, we were engaged upon a novel to be perused for the mere delectation of an idle hour, this would be the place to lay before the reader some of those interesting details which usually occupy a greater or less space in the first volume, wherein it is related how the hero and heroine first met, how they were deeply impressed with each other, how the im-

pression deepened apace,—the tender interviews they had, the impassioned declarations, the obstacles to their happy union—for the course of true love never does run smooth, or at least not before the end of Vol. III. All these and other experiences which befell our heroine shortly before the opening of our story might here be circumstantially related with some effect; but, in the first place, as these particulars are not essential to the course of our narrative as already entered upon; in the second place, as they are perhaps not very different from adventures of the like nature which have befallen other heroes and heroines, and which the fair reader may find already chronicled by more glowing pens than ours; and in the third place, and to conclude, as the *pays du tendre* does not quite lie within our province—so must we be content with prosaically stating that Laura, not long before her visit to the Seymours, had been engaged to a young artist of great abilities, high accomplishments, and unexceptionable principles. The young man was rapidly rising into eminence in his profession; but as, though his landscapes exhibited the greatest talent and promise, Laura's lover had yet to achieve an assured position in the art world, it had been agreed that their union should be postponed for a time. Laura could not expect any considerable dowry from her father; for though Dr. Villiers was in sufficiently easy circumstances from the receipts of his practice, he had not amassed wealth by his profession.

Such, then, was the position when Miss Villiers visited Overton Lodge; her admirer being the meanwhile cultivating his talents with all the energy called into action when the ardour of the lover is added to the enthusiasm of the artist. They were for the present separated; for art is a jealous mistress, and would not suffer Henry Lovell to devote these bright days even to the society of his charming Laura, but had carried him off and hidden him away deep in the forest of Fontainebleau, where he was now courting Nature in her own haunts, and seizing her beauties on his canvas in all their summer freshness. Need we say that at about this time, between the secluded glade in the depth of the ancient forest in France, and the comfortable English home of the Seymours at Overton, there somehow or other passed and repassed not infrequent missives, which, in external appearance, were merely rectangular parallelograms, curiously formed of white paper?

Does the reader suppose that the geometrical terms which

have just escaped from our pen have been clumsily introduced with a view of palliating the literary offence of deliberately placing at the head of this chapter a motto which has no obvious reference to the contents of the chapter itself? But we feel sure that if the foregoing paragraphs are to be considered as a digression from the proposed subject of the chapter, the reader will still be satisfied to condone the irregularity for the sake of its occasion. On the other hand, some reader—we fear it may be one of the gentler sex—may be shocked or perplexed by the introduction of such unexpected and unexplained terms into a simple narrative. If such a reader there be, we now cordially invite her (or him) to step once more into the library at Overton Lodge, where the children had now arranged themselves around the table, in order to consider the several mathematical figures and terms, a knowledge of which their father told them was essential to their future progress. Should any of our readers decline accompanying us through this less flowery path, they may make a short cut, and join us again at the beginning of the following chapter, although we warn such that it is more than probable we shall start some game in our progress.

"As to mathematical figures," said Tom, "if you allude to squares, circles, and figures of that description, and to parallel lines, angles, and so on, I can assure you that I am already well acquainted with the subject."

"If that be the case," replied Mr. Seymour, "you will not have any difficulty in answering my questions; but we must, nevertheless, go regularly through the subject for the sake of your sisters, who may not be equally proficient in this elementary part of geometry. Tell me, therefore, in the first place, what is meant by a *parallelogram?*"

"A four-sided figure," answered Tom.

"That is true; but are there not some other conditions annexed to it?"

"Yes; its opposite sides are parallel."

"And what do you understand by the term *parallel?*"

"Lines are said to be parallel," said Tom, "when they are always at the same distance from each other, and which, therefore, can never meet, though ever so far continued."

"You are quite right. What is a *square?*"

"A four-sided figure, in which the sides are all equal, and its angles all right angles."

"Good again; but let me see whether you have a correct notion of the nature of an angle."

"An angle is the inclination between two lines meeting in a point."

Mr. Seymour here acknowledged himself perfectly satisfied with his son's answers, and said that he should accordingly direct his attention more particularly to Louisa and Fanny; and taking his pencil, he sketched the annexed figure (Fig. 33).

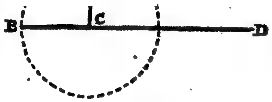


Fig. 33.

"You perceive, Louisa," said her father, "that the line A C makes two angles with the line B D, viz., the angle A C D and the angle A C B; and you perceive that these two angles are equal to each other."

"How can they be equal?" cried Fanny, "for the lines are of very different lengths."

"An angle, my dear girl, is not measured by the *length* of the lines, but by their slope or inclination."

"But, surely," said Louisa, "that amounts to the same thing, for the longer the lines are, the greater must be the opening between them."

"Take the pair of compasses," replied her father, "and describe a circle around these angles, making the angular point C its centre."

"To what extent am I to open them?"

"That is quite immaterial: you may draw your circle of any magnitude you please, provided it cuts both the lines of the angles we are about to measure. All circles, of whatever dimensions, are supposed to be divided into 360 parts, called *degrees;* the size, but not the number, of such degrees will therefore increase with the magnitude of the circle. And since the opening of an angle can always be regarded as a portion of a circle at whose centre the lines meet, it must embrace a certain number of degrees; and two angles are, accordingly, said to be equal when they contain an equal number of them. But there is a very simple way in which you may convince yourself of the equality of the angle A C B and A C D; and that is by taking your scissors and cutting out the portion of the paper between A C and C B, which you will find on trial will exactly fit into the space between the lines A C and C D."

"Now I understand it," said Louisa: "as the dimensions of an angle depend upon the number of degrees contained between its lines, it evidently must be the *opening*, and not the *length* of the lines, that determines the measure of the angle."

"Say, rather, the *value* of the angle, for that is the usual expression; but I perceive you understand me. Tell me, therefore, how many degrees are contained in each of the two angles formed by one line falling perpendicularly on another, as in the above figure."

"I perceive that the two angles together are just equal to half the circle; and since you say that the whole circle is divided into 360 degrees, each angle must measure 90 of them, or the two together make up 180."

"You are quite right, and I beg you to remember that an angle of 90 degrees is called a *right* angle; and that when one line is perpendicular to another, it will always form, as you have just seen, a right angle on either side."

"I now understand," said Louisa, "what is meant by lines being at *right angles to each other;* but, papa," continued she, "what are *obtuse* and *acute* angles, of which I have so often heard you speak?"

Mr. Seymour replied that he could better explain their nature by a drawing than by any verbal description.

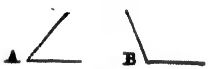


Fig. 34.

"Here," said he, "is an acute angle, A (Fig. 34); and here an obtuse one, B: the former, you perceive, is one that contains less than 90 degrees; the latter one which contains more, and is consequently greater than a right angle."

Louisa fully comprehended the explanation, and observed that she should remember, whenever an angle measured less than a *right* angle, that it was *acute*, and when more, *obtuse*.

"But you have not yet explained to me," she continued, "the meaning of a *triangle*."

"That is a term denoting a figure of three sides and angles. I dare say Tom can describe the several kinds of triangles."

Tom accordingly took the pencil and drew a set of figures, of which the annexed are faithful copies (Fig. 35).

"A," said he, "is an *equilateral* triangle, its three sides being all equal; B is a *right-angled* triangle, having one right angle; C represents an *obtuse-angled* triangle, it having one obtuse angle.

An *acute-angled* triangle is one in which all the three angles are acute, as represented in A."

"As you have succeeded so well in your explanation of a triangle, let us see whether you can describe the nature of a circle."

"It is a round line, every part of which is equally distant from the centre."

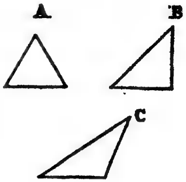


Fig. 35.

"Your answer is somewhat clumsy, but not so bad as that of the candidate for a Government appointment, who recently, in his mathematical examination paper, defined the circle as a straight line with its ends joined! The round line, as you term it, is not, properly speaking, the circle, which is the space bounded by the curve; and the latter is called the circumference of the circle, though for the sake of brevity, the circumference is sometimes referred to as the circle. What is the diameter?"

"A straight line drawn through the centre, and terminating in the circumference on both sides."

"And an arc?" said Mr. Seymour.

"Any portion of the circumference."

"Now, let me ask you, what name is given to a line which joins any two opposite angles of a four-sided figure?"

"The *diagonal*, papa."

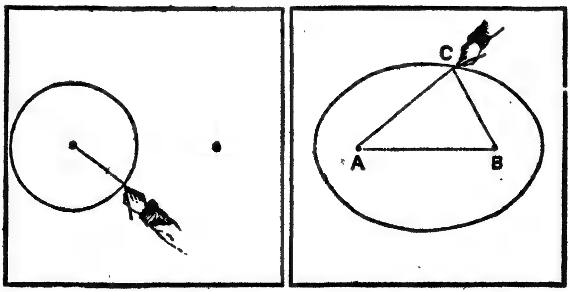


Fig. 36.

"There is one other figure you ought to know something about, because it is the form of the orbits in which the planets

move round the sun. It is called the *ellipse;* and if you will give me two pins and a piece of thread, I will draw an ellipse for you on this drawing-board."

Mr. Seymour tied some of the thread into a loop or endless line, and having stuck the two pins firmly into the board with their heads pointing a little away from each other, he placed the thread over them, and then applying a sharply-pointed pencil inside of the thread so as to stretch it, he struck the curve as shown in Fig. 36. He called the children's attention to the fact of the curve of the ellipse being such that the sum of the distances of each point from the two fixed points, A and B, is always the same, being in the ellipse he had just drawn equal to the length of the thread, less the distance A B. He also informed them that the points A and B were called the *foci* of the ellipse. He also described the circle as shown in the figure, to explain that if the foci of the ellipse were to be placed ever so near each other, the figure would become identical with the circle.

"But I really think," continued he, "that Tom is as capable of instructing you in these elementary principles as myself. I shall therefore desire you, my dear boy, to conclude this lecture during my absence. Remember that by teaching others we always instruct ourselves; but, before I quit you, I will give you a riddle to solve, for I well know that you all delight in an enigma."

"Indeed do we!" said Louisa.

"Pray let us hear it, papa!" cried Fanny.

Mr. Seymour then recited the following lines, which he had hastily composed—the point having, no doubt, been suggested, on the instant, by the remark he had just offered:

"Here 's a riddle for those who delight in their gold,
Which they p'rhaps may explain when my story is told;
No treasure 's so precious, and yet those who gain me,
Though they give me away, will always retain me!
Indeed, if they wish to increase their rich store,
By giving away, they will only add more!!
To Fancy's quick eye, in what forms have I risen!
And poets declare that my birth was in heaven;
To some as a flame, as a stream, or a fountain,
To others I seem as a tower or mountain.
Should these hints not betray me, I only can say
You do not possess me, but I hope that you may."

"Why," cried Tom, "what can that be, of which the more we give away the more we have left?"

"Ay," added Louisa, "and that we actually *increase* the store, by *giving away* a part of it!"

"It is some word, I think," observed Fanny: "do you not remember that mamma asked us what that was, from which we might take away *some*, and yet that the *whole* would remain?"

"To be sure," cried Tom, "I remember it well; it was the word *wholesome*."

Mr. Seymour here assured them that the enigma they had just heard did not depend upon any verbal quibble; and that as the object of its introduction was to instruct rather than to puzzle them, he would explain it, and leave them to extract its moral and profit by its application.

"It is KNOWLEDGE," said he.

"'No treasure's so precious,'" repeated Louisa, "certainly none; 'and yet those who gain me, though they give me away, will always retain me;' to be sure," added she. "How could I have been so simple as not to have guessed it? We can certainly impart all the knowledge we possess, and yet not lose any of it ourselves."

"By instructing others," said Mr. Seymour, "we are certain at the same time of instructing ourselves, and thus to increase our store of knowledge: let this truth be impressed upon your memory, and, after our conversations, examine each other as to the knowledge you have gained by them; you will thus not only fix the facts more strongly in your recollection, but you will acquire a facility of conversing in philosophical language. I must now quit you, in order to attend to some business which will fully occupy me until the dinner-hour."

In the evening Mr. Seymour presented the children with a toy which he hoped would serve as an illustration of a geometrical idea with which he wished them to be acquainted. It was simply a contrivance designed to give a very rapid whirling motion to little pieces of wire, which severally fitted into a socket, so that they might be easily made to replace each other at pleasure. The pieces of wire were formed of various shapes; and when one of them was made, by turning the handle of the little machine, to rotate very quickly about a fixed axis, it was no longer perceptible as a piece of wire, but a delicate transparent form seemed to be shaped out in the air. The principle upon which these forms were produced was immediately recognized by the young people as identical with that which caused

the glowing stick to appear like a circle of fire. In like manner a piece of wire in the form of a semicircle produced in the new toy the appearance of a globe, and pieces variously bent gave rise to seeming shapes of vases, cups, balusters, bottles, &c.

"This toy will not fail," said Mr. Seymour, "to give you a clear idea of the kind of forms mathematicians call *surfaces of revolution*, and of the mode in which they are produced."

To one the figures formed in this way Mr. Seymour directed their particular attention. It was produced by a wire of this form,

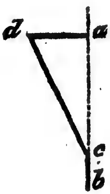


Fig. 37.

which, when the part marked *b* was fastened in the socket, could be whirled about the axis, *a b*, and it then gave rise to the form of a *cone*—the portion *a d* producing a flat disc or circle; while *d c* swept out, and caused to be visible the curved surface of the cone, the apex of which was at *c*. Some of the juveniles at once pronounced this form to be shaped like an extinguisher; others were reminded of a sugarloaf. Their father told them that the cone was one of the most interesting of geometrical solids, because certain curves which are produced by cutting a cone in different directions had much engaged the attention of geometers, who had discovered many remarkable properties of the *conic sections*, as these are called.

Tom said he had often heard of *conic sections*, and begged his

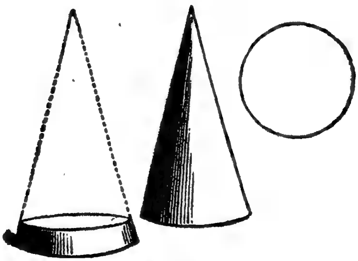


Fig. 38.

father to explain what they were. Mr. Seymour accordingly produced wooden models showing the cone cut in various ways. One of these is represented in Fig. 38: here the cone is cut so that a slice appeared to be taken off its base, and the

purpose of the model was, Mr. Seymour said, to show that when a cone is cut by a plane parallel to its base, the section is a *circle*. Another model was shown in which the cone was cut in the manner represented in Fig. 39; and the children at once

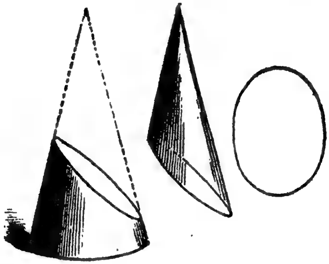


Fig. 39.

recognized that the form of section was in this case an *ellipse*. He also demonstrated, by help of the models, that besides these two figures, two other sorts of curves are produced by cutting the cone in certain other directions.

"These curves," said he, "are termed respectively the *parabola* and the *hyperbola*. Thus there are in all four different

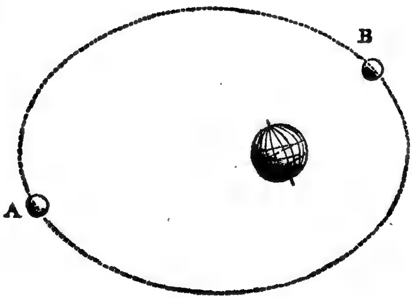


Fig. 40.

curves, one or other of which every section of a cone must produce according to the direction of the plane of section with respect to the cone. Great interest attaches to these curves,

because the orbits of the planets, comets, and other heavenly bodies, are always one or other of the conic sections. Here, for instance, we may represent the orbit of the moon about the earth," continued Mr. Seymour, taking a paper on which Tom had struck an ellipse, and sketching conventional representations of the earth at one of the foci, and of the moon at two points of her orbit, precisely as in the annexed figure (Fig. 40); "only you must understand that in the real orbit, the foci of the ellipse are proportionately much nearer each other, so that the greatest and least distances of our satellite are, in fact, about as 10 to 9, instead of as 2 to 1, which our diagram would appear to show."

These observations led to many inquiries on the part of the young people; but Mr. Seymour told them that they had so much to learn about motion and forces, that he must postpone the discussion of the fascinating subject of celestial mechanics until their studies were more advanced. He promised that he would, the next morning, try to lead them to some distinct ideas about motion, and that would clear the way for the consideration of the great law of gravitation which controlled the heavens. Accordingly, when his juvenile audience had assembled the next morning on the lawn, he held with them the conversation which is related in the following chapter.

CHAPTER X.

Thus day and night, and star and flood,
And seasons—all attest
That through the wondrous works of God
There's nought remains at rest.

"I PROPOSE now to consider with you certain notions which underlie the whole fabric of physical science. You may perhaps wonder why I did not set these fundamental facts before you at the very commencement of our studies. Well, I have been hoping that, by such reasonings as we have already gone through, your minds have been imbued with some slight tincture of scientific thought, and that the experience you have gained of certain facts will assist your comprehension; for the subjects we are going to discuss are by no means so easy to grasp as the facts and laws you have now fairly understood. Besides, in pursuing this course we are, to a certain degree, following the path by which knowledge has advanced among mankind;

for the first principles of a science are usually the latest to be arrived at, and the laws which are highest in the order of generality and importance, come last in the order of discovery. And now, as we have hitherto made some toy or game furnish a subject for our discourse, let us on this occasion take this ball, and see to what inquiries it will lead us. There it goes along the level path, and you see that it has two motions at the same time, for it not only advances in a straight line, but it also rolls on the ground, turning about a horizontal axis."

Tom said he did not quite understand what was meant by an axis. His father informed him that the axis of a revolving body is the imaginary line which would pass through the centres of all the circles described by the different parts of the body, for every point in a revolving body describes a circle, except only those which are in the axis itself. "But can you tell me," he continued, "whether you understand what is meant by the word *motion?*"

"If he can," exclaimed the vicar, "he is a cleverer fellow than the wisest philosopher of antiquity, who, upon being asked the very same question, walked across the room and replied, 'You see it, but what it is I cannot tell you.'"

"I think he gave an excellent answer," observed Mr. Seymour, "for as the word expresses some of the most elementary facts of our experience, there is nothing simpler into which the idea can be resolved. If we attempt to give a definition—if, for example, we say that motion is the act of a body changing its position with regard to any other body—we only use a number of words instead of one. As motion, then, is known to every person by his own experience, so also certain varieties, degrees, or modes of motion are similarly known, and the words which express them cannot be made more intelligible by formal definitions. Thus every one understands what is meant by motion in a straight line, or by one motion being faster or slower than another, or by a motion becoming gradually quicker, because his own experience has furnished him with numberless examples of such motions. But, being thus already in possession of these elementary ideas of motion, we may proceed to extend our knowledge of motions by more careful comparisons of different cases. The first thing that is necessary is, then, a measure of motion, or some standard of comparison more exact than the impressions we directly receive from the motions themselves.

It is obvious that the measure of motion includes time and length, and that if two bodies move during the same period of time, or during equal periods of time, that which passes over the greater length of path has the quicker motion, or the greater velocity; and, on the other hand, if the same length of path or space is passed over by two bodies, that one which takes the less time to do it has the greater velocity. Thus the velocity varies directly as the space passed over, and inversely as the time, and it is, therefore, expressed by a number obtained by dividing the number representing the space by that representing the time; or, what comes to the same thing, a uniform velocity is measured by the number of units of space which the body passes over in a unit of time. Thus, if the ball runs over 10 feet in two seconds, its velocity is $\frac{10}{2} = 5$. And you should notice that the number expressing the velocity of a uniform motion is the same whether we take the space passed over in a short or a long interval of time. For instance, the space passed over by the ball, in the case supposed, is plainly 1 inch in each sixtieth part of a second. Keeping to the former units, we find the velocity thus: $\frac{\frac{1}{12}}{\frac{1}{60}}$; and get 5 as before.

"There is a distinction made between *relative* and *absolute* motion, which I must try to explain to you. Let us suppose that Tom were to bowl his ball along the deck of a steamer; would it make any difference with regard to the motion of the ball on the deck if the steamer were in motion?"

"No," said Tom, "I am sure it would not, for I remember once trying with a ball in a saloon railway carriage, to see whether the ball would move faster or slower according as I bowled it in the direction the train was moving or in the contrary direction, and I could find no difference whatever."

"Yet the ball must move quicker in one case than in the other," said Louisa.

"Tom's observation was correct," said Mr. Seymour, "for the ball would in either case move along the floor of the carriage in exactly the same way whether the train were in motion or stationary. And yet Louisa is not wrong, for she was thinking of the motion of the ball not so much with regard to the carriage as with reference to the railway itself. The motion of the ball is very different according as we refer it to the carriage or to the ground. Thus, let us suppose that Tom had bowled his

ball backwards with exactly the same velocity as that of the train forwards, then the ball might be described as standing still in reference to the ground."

"Well, that surpasses all the paradoxes I ever heard," cried Tom; "a body may, then, be in motion and at rest at the same time."

"Certainly," replied Mr. Seymour; "and in the case we have just been supposing, your ball might be described as relatively in motion and absolutely at rest. But I think that we should find, on considering the subject more closely, that the term *absolute* can itself be used but relatively. The ball which has no motion with regard to the earth is not at rest, because it partakes of those motions which belong to the earth. The sun is known to be moving relatively to the fixed stars, and, for anything we know, the stellar universe, as a whole, may be careering through space. But we shall never be able to affirm that this is either in motion or at rest, for there is nothing beyond by which to judge. Absolute motion and absolute rest are, therefore, by us unknown and unknowable. But the words absolute and relative may be, nevertheless, useful to distinguish actual change of place in the common acceptation of the term from that which is apparent only."

"But surely, papa," said Louisa, "when a body really moves, we can observe it in the act of changing its place, and there can be little use in seeking terms to distinguish that which no one is ever likely to confound."

"But it is precisely because our observations are often fallacious, and require correction by comparisons and reasonings, that these distinctions are necessary. Thus the earth appears motionless, and the sun and stars seem to revolve about it, whereas we know that the contrary is the case. You must also frequently have observed, when a railway train has been passing another in which you have been seated, you have supposed your own train to be in motion, and have only been undeceived when the other train has passed. And again, when two trains are moving in the same direction on parallel lines, curious illusions of a similar kind may sometimes be noticed. Thus, the one in which you are seated may appear to be slackening its speed, become stationary, and even seem to retrograde, and all this merely by reason of the other train increasing its speed. A well-known aëronaut," continued Mr. Seymour, "informed me

that he was never sensible of the motion of the balloon in any of his excursions, but that, as he ascended into the air, the earth always appeared as if sinking beneath him."

Mr. Goodenough here observed that he had heard a very curious anecdote, when he was last in London, which fully confirmed the truth of Mr. Seymour's statement. "An aëronaut," said he, "whose name I cannot at this moment recollect, had published a map of his voyage, in which his course, instead of proceeding in any one direction, appeared entirely in the form of circles, connected with each other like the links of a chain: this occasioned considerable astonishment, and, of course, some speculation, until it was at length discovered that this strange journey was apparent only, and due to a rotatory motion of the balloon, which the voyager, not feeling, had never suspected."

"And what," asked Tom, "could have been the reason of his not having felt the motion?"

His father explained to him that we are only conscious of being in motion when the conveyance in which we are placed suffers some impediment in its progress. "If," said he, "you were to close your eyes when sailing on calm water, with a steady breeze, you would not perceive that you were moving; for you could not feel the motion, and you could only see it by observing the change of place in the different objects on the shore; and even then it would be almost impossible, without the aid of reason and experience, to believe that the shore itself was not in motion, and that you were not at rest."

Mrs. Seymour here repeated from Hope's novel "Anastasius" the following passage, which, she observed, was beautifully descriptive of the illusive appearance to which their papa had just referred:

"'The gradually increasing breeze carried us rapidly out of the Straits of Chio. The different objects on the shore—mountains, valleys, villages, and steeples—seemed in swift succession first advancing to meet us, then halting an instant alongside our vessel, as if to greet us on our passage, and lastly, again gliding off with equal speed; till, launched into the open main, we saw the whole line of coast gradually dissolve in distant darkness.'"

"That is indeed an elegant and very apposite illustration," said Mr. Seymour; "and I think Louisa will now admit that it

is not quite so easy as she at first imagined to distinguish between absolute and relative motion.

"Now that we have considered the nature of the distinction between these terms, I must ask you to study something more about motion before we proceed with our experiments. We have said nothing about variable motion, although it is very necessary you should know something about certain cases of motion of this kind. If a railway train takes five hours to travel from Manchester to London, a distance which we will call 200 miles, we say it has an *average velocity* of 40 miles an hour, and this number is obtained by dividing the distance by the time, just as in the case of a velocity really uniform. But, as you know very well, the train, as a matter of fact, would by no means have this speed throughout the journey, because for a portion of the time it might be stopped at certain stations, and in leaving and stopping at each its speed would be gained and destroyed gradually; while at other parts of its course the speed might be 50 miles an hour. Can you tell me, Tom, how you would measure the velocity at which such a train passed a given point on the line, if its speed were thus constantly varying?"

Tom thought a little.

"It certainly would have nothing to do with the number of miles passed over in the next hour or in the hour before. I think I should get something near the rate per hour if I took the distance passed over by the train during the next minute, and multiplied it by 60."

"But don't you think it would be still nearer if you were to measure the space passed over during the next *second*, and multiply that by 60 times 60?"

"Yes, of course, that would be nearer the truth; for I see that the speed might be very different throughout a whole minute. But might it not also vary even in the space of a second?"

"Undoubtedly it might," replied Mr. Seymour, "and such a measurement of a variable velocity at a particular instant would not be true even if you took a second. You will easily understand, however, that the error must lie within narrower limits in this case than in the other. It is plain, also, that if you could take a still less period of time in which the space passed over could be measured, the result would be still nearer the truth. In every case of a variable velocity, the real velocity at any particu-

lar instant is the space that would be passed in the unit of time if the velocity were to continue uniform from the instant under consideration. And in measuring such a velocity we can obtain as near an approximation as we please by taking the interval of time in which the space is measured sufficiently short."

"I perceive that in measuring variable motion," said Tom, "it is not, as in uniform motion, a matter of indifference what intervals of time we take."

"I wish you now to reflect how a motion may be such as to have a uniformity in its variation. Thus, suppose that the moving body increases its velocity by the same amount in each successive interval of time, however small that interval may be, it is said to have a uniformly accelerated velocity. For instance, if a railway train at the end of the first second after starting is moving at the rate of 3 feet per second, and continues to gain the same increase of velocity each succeeding second, so that *at the end* of the 2nd, 3rd, 4th, 5th, &c., seconds, it would have the respective speeds of 6, 9, 12, 15, &c., feet per second, we should call it a case of uniformly accelerated motion, provided always that the increase was uniform during each second—that is, that in each third of a second a foot per second of velocity was added; in each 36th part of a second, 1 inch per second; in each 360th part of a second, $\frac{1}{10}$th of an inch; and so on. Now, in ordinary language, the word 'acceleration' is applied to the act of increasing speed; but in science a technical sense is attached to this term; for it is used, not as an abstract term denoting the act of accelerating, but as an expression for the velocities which are added to, or taken from, variable motions in each unit of time. Thus, the train in the case I have just supposed would be said to have an acceleration of 3 feet per second."

"But when there is a loss of speed, would not that be called *retardation?*" asked Tom.

"We speak of retarded motion," replied Mr. Seymour, "but the term 'acceleration' is generally used to express also loss of motion, its amount being then taken *negatively*. But can you show us with your ball some instances of accelerated and retarded motions?"

"Oh, yes!" cried Tom, suiting the action to the word: "I place the ball upon this smooth gently-sloping path, and it is beginning to roll down very slowly; but now it is gathering speed, and there it goes bounding down at a very great speed.

When I bowl it up the incline, its motion becomes slower and slower, until the ball actually comes to rest. But, pray tell me, what are the terms which should be applied to distinguish the movement of the ball along the ground from its spinning motion?"

"The former is said to be a motion of *translation*," replied Mr. Seymour, "and the latter a motion of *rotation*. There are certain other terms employed in speaking of motions; but I will only refer to one, namely, *oscillatory* motion, which is applied to a body that describes one path in opposite directions alternately."

"Before I leave," continued Mr. Seymour, "the subject of motion, there is another point I should like to make clear to you all, for it will enable us to make use of a term by which other facts may be more easily explained. I must ask you to accompanying me to the billiard-room, where I can give you an easy illustration of my meaning."

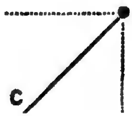


Fig. 41.

To the billiard-room the whole party accordingly proceeded, where Mr. Seymour, having drawn on the table with a piece of chalk the oblique line A C (Fig. 41), placed a ball at A, and then asked what would be the measure of the velocity of the ball if it were made to move uniformly along the line from A to C. Tom promptly replied that the velocity in inches and seconds would be expressed by the number obtained by dividing the number

of inches in A C by the number of seconds occupied by the ball in passing from A to C.

"Quite right," said Mr. Seymour; "now, if, while the ball is moving along the line A C, I could move this cue (A D) always parallel to the side C E of the table, and always in a line with the ball, so that it and A D should ever be at the same distance from the side C E of the rectangular table, or what is properly the essential condition, so that the cue should always point to the ball, and be always perpendicular to the side D E, I think you would see that D would move along D E with a uniform velocity, and as D E is shorter than A C, this velocity would be less than the velocity of the ball. You must try to remember that the velocity of D along D E is called the *velocity* of the ball *resolved* along D E. We can resolve the original velocity in A C along any other direction we choose; for example, if a line A B, always perpendicular to C E, followed the ball in its journey from A to C, then the velocity of B would be the velocity of the ball resolved along the side B C of the table. You will easily see that the resolved velocities will always be less than the original one; and also that if I draw the line A C so that the angle A C B is less, the *component*, as it is called, along E C will be larger, and that along D E smaller, than before. If the ball be made to move in the line A H with a velocity = V, the resolved *components* along E C and D E will be V and *nil* respectively. Again, you will notice that if the cues were moved perpendicularly along the sides of the table with the resolved velocities, the intersection of their directions would advance on the table so as to reproduce exactly the corresponding movement of the ball."

As the young people now appeared to have gained some idea of the meanings of the terms most necessary for defining motions, Mr. Seymour asked whether any of them could tell by what means motion is produced.

"I can make a body move by various means," answered Tom.

"But philosophers have agreed," said Mr. Seymour, "to call that which changes, or tends to change, the condition of a body with regard to its state of motion or rest, by the name of Force. To impart motion to a body previously at rest is only one form of this change, for the increase, diminution, or destruction of the velocity of any body in motion is equally due to force, as is also any change in the direction of a body's motion; so also that which prevents a body from moving when acted on by a

force is itself a force. In fact, there are only two conditions possible for bodies unacted on by any force—namely, absolute rest, or motion in a straight line with a uniform velocity for ever."

"For ever!" exclaimed Louisa.

"Ah, my dear, for ever; and I shall presently point out what kind of facts justify such a statement."

Tom here remarked that he should like to know something more about force, which Mr. Seymour had only spoken of as a mere word for expressing whatever causes a body to move or stop, or in any way alter its movements.

"I should like," said he, "to hear what force is when it is not acting on a body. As you have been talking about motion without mentioning force, would it not be possible for us to consider force without motion? For I know that I can exert force without producing motion, as when I press my hands together, or push against a wall, and the feeling is exactly the same as when I move the garden roller or anything else by pushing."

"Your observation is perfectly correct as regards the sensations which one experiences when the muscles are exerted in any of the ways you have mentioned, and it is this kind of consciousness which has caused us to have such a word as *force*; but in the case of one hand pressed against the other or against a wall, there is present to the mind the idea of motion resisted. For this state of things is only a particular case of the action of forces, which here neutralize each other, so that the motion which either would produce is prevented by the other. And I must tell you that such experiences as the three you have just mentioned, in all of which the sensation of muscular exertion is exactly the same, are the ultimate sources of the notions expressed by the terms *force*, *matter*, and *inertia*. In truth, matter, resistance, force, motion, and inertia, are not separate things, but expressions for the same fact of our experience, viewed, so to speak, from different sides. By reflecting on what is really implied in all these terms, you will come to the conclusion that in nature the fact is one and indivisible, however we may contemplate it, and however many different terms we may find it convenient to use for its expression. It would be a great mistake to suppose that for each different word made use of there must necessarily exist in nature a separate and independent corresponding thing. But there is an obvious advantage in

having phrases which shall bring before the mind one or another aspect of the same fact, according to the relation in which it has to be viewed. Hence, when we attempt to frame a definition of any one of those terms by help of the others, we merely repeat what is already necessarily included in the expression we define, and without which it cannot be thought of. Thus we know nothing of motion except as some *thing*, some *body*, moving; and if from that which we mean by matter we suppose all that is expressed by force to be removed, there would be nothing left. And, again, force cannot be conceived of except in connection with the actual or obstructed motions of bodies. It is necessary to enter into these considerations, because many people are entirely misled by such terms. For instance, there is a popular notion that force is something outside of matter, which is imagined to be merely the inert stuff upon which force operates; that momentum and inertia are distinct "powers;" and so on. Thus it happens that these terms are frequently used in reasoning, under the same fallacy which is ludicrously obvious in the sapient conclusion of the gravedigger in 'Hamlet'—

"'He that is not guilty of his own death, shortens not his own life.'

But come, Tom, roll the ball hither; roll the ball hither, I say. You stand as if you thought it would advance of its own accord."

"I know a little better than that, too," cried Tom; "no body can move without the application of some force."

"Nor stop either," added Mr. Seymour, "when it is once in motion, for matter is equally indifferent to both rest and motion."

"And yet, papa," cried Louisa, "unfortunately for your assertion, the ball stopped just now, and I am sure that no force was used to make it do so."

"And pray, Miss Pert, why are you so sure that no force was opposed to its progress? I begin to fear that my lesson has been thrown away upon you, or you would not have arrived at so erroneous a conclusion."

The vicar here interposed, observing that, simple as it might appear to those who had studied it, the fact was so contrary to everything that passed before us, that Mr. Seymour ought not to feel any surprise at the scepticism of his daughter. He begged to remind him that the truth lay hid for ages before the sagacity of Galileo brought it to light.

Mr. Seymour admitted the justice of this remark; "for," said he, "the conclusion that every moving body stops of its own accord is, after all, only a just inference from ordinary observation, which overlooks the obstacles a moving body encounters—the rubbing or friction occasioned by its passage over the ground, and the resistance offered by the atmosphere."

Tom asked if these opposing forces could not be in some way removed.

"It is out of our power entirely to remove these," replied Mr. Seymour, "but the experimental proofs of their effect in destroying motion is almost as cogent as if we could. For although we cannot entirely abolish them, we can greatly diminish them, and it is found that the retardation of motion always is diminished in precisely the same degree. I say in precisely the same degree, for the effect of the opposing forces in destroying motion may be estimated. But let me remind you of instances which will illustrate this point. Louisa has doubtless often noticed the difference between the movements of the balls on the croquet lawn, when the grass has been long, and when it has been mown and the lawn recently rolled."

"Oh, yes, papa: in the latter case the balls will run much faster and farther."

"And if you tried how a ball would run on the level asphalted walk, you would find that, with a blow of equal force, it would be still longer in coming to rest. As further illustrations I might name the difference, well known to experienced billiard players, of the movement of the balls on a new cloth, and on one the protruding fibres of which have been worn off; and again, the prolonged motion which is obtained in skating is owing entirely to the smoothness of the surface. But the resistance of the atmosphere to the motion of bodies is also very considerable. A French *savant*, in some experiments on the oscillations of suspended bodies, caused a weight, hung up by a wire, to swing backwards and forwards for thirty hours from a single impulse given to it, because the movement was made to take place in a vacuum, whereas in ordinary circumstances the weight would have come to rest in a few minutes."

The vicar here observed that the rotation of the earth on its axis was an instance of the uniformity of motion when no forces interfered to change it.

"Yes," said Mr. Seymour, "it is this motion which supplies

us with the standard by which we estimate periods of time. And, in fact, if we are called upon to define the meaning of equal periods of time, we are compelled to say that we mean those periods during which the earth turns through equal angles; so that, you see, even our common measure of time implies the assumption of a moving body continuing to move without change. But now I will give you the words in which Newton expressed this great truth of the persistence of motion. He said, 'Every body perseveres in its state of rest or of uniform motion in a straight line, except in so far as it may be compelled to change that state by impressed forces.'"

"Then it follows," remarked Louisa, "that all the bodies on the surface of the earth are constantly acted on by some force, for we now know these bodies are neither at rest nor moving in a straight line."

"Your deduction is perfectly correct," replied Mr. Seymour, "and we shall shortly have to study the operation of this force."

"Louisa's remark," said the vicar, "reminds me how entirely opposite to Newton's axiom was the doctrine held by the ancients, who affirmed that the only perfect motion was in circles."

"Since a body at rest," continued Mr. Seymour, "can only be set in motion by the impression of some force, it must follow that it can only move in the direction in which the force acts; and, moreover, that the degree of motion or the *velocity* must, other things being equal, be in proportion to the degree of force used."

"Why, truly," cried the vicar, "my young friends must of necessity admit that fact, for the body, not having any will of its own, as you say, must needs, if it move at all, go the road it is driven."

"Yes," added Mr. Seymour, "and it must go with a velocity proportional to the force with which it is driven. For from the very idea of force there can be no other ultimate measure of it than velocity; so that if one force applied to a body causes it to move with double the velocity which would be produced by another similarly applied to the same body, we are compelled to consider the first force just double the other, and so on."

"Doubtless, doubtless," cried the vicar; "you admit that also, do you not, my young friends and playmates?"

"But I must impress upon you that in making such a com-

parison all the circumstances of the action of the two forces must be the same in the two cases. They must act upon the same body, or, if upon different bodies, the equivalency of these in regard to the point in question must have been established. They must also act in the same manner on the bodies and for the same interval of time, the bodies being free to move in the direction in which the forces impel them. If you have understood and will carefully reflect upon the results we have now arrived at, I shall have but little difficulty in explaining the laws which govern moving bodies. You will find these to be extremely few, simple, and consistent. Let me again remind you that the difficulties in this subject arise mainly from the number of terms which are used to express different aspects of the same fundamental fact. Thus, the fact that force must be applied to a body at rest in order to produce motion, and also to a body in motion in order to bring it to rest, is expressed by the word *inertia*, the fact being then viewed chiefly as a property of matter. This law or axiom of Newton's includes really, but not formally, definitions of inertia, of force, and of matter. But as your attention has been severely taxed this morning, we will now adjourn for lunch, and a little exercise in the open air, after which we shall meet again on the lawn at two o'clock."

Just as Mr. Seymour and the vicar were at the appointed hour stepping upon the lawn with the intention of joining the children, Rosa and Fanny both made their appearance completely drenched with water, and dripping like mermaids.

"Heyday!" exclaimed their father, "how has this misfortune happened?"

"Do not be angry, papa," said Tom; "indeed, indeed, it was an accident. Fanny, observing the water-cart in the garden, had just begun to wheel it forward, when the water rushed over her like a wave of the sea, and, upon stopping the cart, it flew over with equal force on the opposite side, and deluged poor Rosa, who was walking in front of it."

"Well, well, lose no time in changing your clothes, and meet us here again in half an hour."

When the girls reappeared their father addressed them with assumed severity. "I perceive," said he, "that my philosophical lesson of this morning has been entirely lost upon you. I trust, however, that this accident will serve to impress it more forcibly upon your memory: one example is better than a hundred pre-

cepts. I will endeavour to convert your accident into a source of instruction by showing you how the principles of natural philosophy may be brought to bear upon the most trivial concerns of life. The butt was full of water. When you attempted to wheel it forward, the water did not at once receive the motion thus communicated to the vessel, and from its *inertia*, or tendency to remain at rest, rose up in a direction contrary to that in which the vessel moved, and consequently poured over. By this time, however, the mass of fluid had acquired the motion of the cart, when you suddenly stopped it, and the water, in endeavouring to continue its state of motion, from the same cause that it had just before resisted it, rose up on the opposite side, and thus saturated our unlucky Rosa."

Louisa was quite delighted with this simple and satisfactory application of philosophy, and observed that she should not herself mind a thorough soaking if it were afterwards rewarded by a scientific discovery.

"I will give you, then, another illustration of the same law of motion," said Mr. Seymour, "which, instead of explaining an accident, may, perhaps, have the effect of preventing one. If, while you are sitting quietly on your horse, the animal starts forward, you will be in danger of falling off *backward;* but if, while you are galloping along, it should stop suddenly, you will inevitably be thrown *forward* over the head of the animal."

"I clearly perceive," said Louisa, "that such would be my fate under the circumstances you state."

Mr. Seymour now proposed that each of the juvenile party should feel for himself the effects of inertia, by observing the effort which was required to set in motion the garden roller, or to stop it quickly when in motion. It was found, in fact, quite impossible either to start or stop it suddenly, and the result of the trials was to give the children a very distinct idea of what is implied by inertia. After this Mr. Seymour asked the party to adjourn to the library, where he had a new toy ready for them, and one or two experiments to show in further illustration of inertia.

To the library they accordingly proceeded, and there Mr. Seymour brought out the new toy, which in reality was a once common but now forgotten amusement, very fashionable about the end of last century. This toy seems to have been invented in France, where it was called the *bandalore*, but the English

called it a *quiz*. To such a degree did the fancy for this toy at one time prevail among people of all ages and ranks, that numbers of persons of both sexes were to be seen playing with the quiz in the streets.

Mr. Goodenough here remarked that the origin of the word quiz was itself not a little curious, if Smart's account of it is the correct one. "He says," continued the vicar, "that Daly, the manager of a Dublin theatre, having laid a wager that he could make a word of no meaning become in twenty-four hours the talk and puzzle of the city, caused the letters Q U I Z to be chalked or placarded on all the walls of Dublin, and with such result that he won the wager."

"That is quite possible," said Mr. Seymour; "and I can bring forward another illustration of the way in which such trifles may take hold of the public mind. What do you think most occupied the minds of the fashionable world in Paris about the year 1811? It was neither the famous comet which was then blazing in the sky, nor the gigantic preparations which were then being made for the fatal march into Russia. The mind of society was not possessed by these things so much as by—your pardon, vicar—*le diable!* I do not mean the dark spirit of evil, or the poetical creation of Milton, or the personage of Meyerbeer's opera, but a toy which was only a slight modification of the bandalore as we have it here. The *diable* was a sort of double humming-top, made to revolve in a manner not unlike the bandalore, by means of a cord passed round the axis and attached to two sticks held in the hand. But I will show you a print, dated 1812, in which you will see a dandy of the period instructing two ladies in the management of the toy." Here Mr. Seymour took a book from one of the shelves, and showed the print, of which Fig. 42 is a reduced copy. "It is here stated," he continued, "that at the Tuileries, in the public gardens, and in the drawing-rooms, every lady and every child was occupied *à faire ronfler le diable*—in making the top hum."

The bandalore which Mr. Seymour now exhibited in action consisted of two discs of wood, united to each other by a small axis, to which a piece of string is attached. When this string is wound round the axis, and the bandalore is suffered to run down from the hand, the end of the string being held by a loop on the forefinger, the rotatory motion acquired in its descent winds up the string again; and thus, with a little dexterity on

Fig. 42.

the part of the operator, it will continue for any length of time to descend from and ascend to the hand. In playing with the bandalore, a certain address is required to prevent the sudden check which the toy would otherwise receive, when it arrives at the end of the string, and which would necessarily so destroy its momentum as to prevent its winding itself up again. It affords a good example of the operation of inertia in the case of rotatory motion. Its action may be compared to that of a wheel, which, running down a hill, acquires sufficient motion to carry it up another. There are several toys which owe their operation to the same principle, of which we may particularize the windmill, whose fliers are pulled round by a string affixed to the axis of the sails.

Mr. Seymour now informed his young pupils that he had an experiment to exhibit, which would further illustrate, in a very pleasing manner, the nature of inertia. He accordingly inverted a wine-glass and placed a shilling on its foot, and having pushed it suddenly along the table, the coin flew off towards the operator, or in a direction opposite to that in which the glass was moving. He then replaced the shilling, and imparted to the glass a less sudden motion, and when it had acquired sufficient velocity, he checked it, and the coin darted forward, leaving the glass behind it. Louisa, upon witnessing this experiment, observed that she felt satisfied of the correctness of her father's statement, when he told her that if the horse suddenly started forward, when she was at rest, she would be thrown off behind, and that if it should suddenly stop on the gallop, she would be precipitated over its head.

In concluding the scientific conversation for that day, Mr. Seymour recommended our young friends to consider well the *first law of motion*, which he hoped they now, to some extent, understood. He trusted this law would be thought of, not as a form of words to be remembered or repeated, but as a short, complete, and really simple statement of what was actually occurring in every movement of the objects around them; and as a principle which, so to speak, governed the actions of their own bodies, as well as the motions of the orbs of heaven. He believed that if they tried to recognize the unceasing operation of this law in the ordinary cases which were continually presenting themselves in their daily life, they would enter with greater advantage upon the subject of *gravitation*, to which he intended next to direct their attention.

Tom and Louisa hereupon stated that they already knew something about gravitation, from having looked into Mrs. Marcet's and other books; and Mr. Seymour then said that he would test their knowledge by asking them some questions on that subject, when next their scientific recreations were resumed.

CHAPTER XI.

Then breaking hence, he took his ardent flight
Through the blue infinite ; and every star
Which the clear-concave of a winter's night
Pours on the eye, or astronomic tube
Far stretching snatches from the dark abyss,
Or such as further in successive skies
To fancy shine alone, at his approach
Blazed into suns ; the living centre each
Of an harmonious system ; all combined
And ruled unerring by that single power
Which draws the stone projected to the ground.

IT was about two o'clock when, a few days afterwards, Mr. Seymour, in company with Mr. Goodenough, joined the children on the lawn, in order to continue the course of scientific illustrations.

"Tom," said his father, "are you prepared to undergo the proposed examination?"

"Quite ready, papa."

"Then you must first inform me," said Mr. Seymour, taking the ball out of Rosa's hand, "why this ball falls to the ground as soon as I withdraw from it the support of my hand?"

"Because every heavy body that is not supported must, of course, fall."

"And every light one also, my boy; but that is no answer to my question: you merely assert the fact, without explaining the reason."

"Oh, now I understand you. It is owing to the force of gravity; the earth attracts the ball, and the consequence is that they both come in contact. Is not that right?"

"But do you think you have now really explained the fact by saying that it is the force of gravity, or the attraction of gravitation, which causes a body to fall? You have, perhaps, again merely varied the terms in which you express it. For tell me what is the meaning of gravity and gravitation?"

"These words," said Tom, "are derived from the Latin *gravis*, 'heavy,' and therefore *gravity* would, I suppose, mean 'heaviness.'"

"If that is all the meaning you attach to the word," said Mr. Seymour, "the explanation you offer us is that the fall of a *heavy* body is owing to the force of *heaviness*."

"Of course that would be absurd," cried Tom. "I perceive I have not explained the fact, but only expressed it in philosophical language."

"There cannot be any philosophy in language which makes words seem to stand for the causes of things, or employs sonorous phrases as if they solved all difficulties."

"And yet," said Louisa, "I have seen it stated in books that Sir Isaac Newton discovered that it is gravitation which draws bodies to the ground, and that their fall is explained by the action of gravity."

"Such a statement tells us nothing whatever, unless we know what is implied in the word 'gravity;' and even then we are no nearer to what is *ordinarily understood* by an explanation than before; for neither Sir Isaac Newton, or any man who ever lived, has been able to say *why* a stone falls to the ground: that remains for us, as for him, a fact which cannot be accounted for by any intermediate agency. But the great glory of Newton was that he showed that the same inexplicable influence pervades the whole universe; that there is not anywhere

a particle of matter throughout the immeasurable realms of space which does not attract every other particle of matter. He proved that the unaccountable fact of bodies being attracted by the earth is only a particular case of a vastly more general but equally unaccountable fact. It is this all-pervading influence, by which each particle of matter draws every other towards it, that Newton called gravitation. Here I must tell you that the philosophical meaning of *explanation* is entirely different from the common sense of the word. In ordinary parlance we are said to *explain* a thing by showing how it is related to some *more familiar* things; whereas, in science, a thing is considered to be explained when it can be referred to facts *more general* than itself. Observe that the more general fact, of which Newton showed the fall of bodies to the earth to be only a particular case, was not only less familiar, but even previously entirely unknown."

"I remember," observed Louisa, "that Mrs. Marcet says that the fall of an apple attracted the attention of Sir Isaac Newton; so that by reflecting upon it he was led to his great discovery, and she extols that apple above all the apples that have ever been sung by the poets; and she declares that the apple presented to Venus by Paris, the golden apples for the sake of which Atalanta lost the race, nay, even the apple which William Tell shot from the head of his own son, cannot be brought into comparison with it."

"Well said, Mrs. Marcet!" exclaimed Mr. Seymour; "upon my word, we cannot wonder at the effect on Adam if the mother of mankind used as much eloquence in praise of her apple. But whether this story about Newton be true or not, it is certain he was led to consider that as a body—let us assume it is an apple detached from the top of a tree—is drawn to the ground, and as the same thing would take place were the tree even as high as a mountain—for we know that this force is in operation on the loftiest peaks—so, if the force extends to so high, why not higher, far above the surface of the earth? Nay, asked Newton, why may not this be the very power which retains the moon in her curved orbit round the earth? I must tell you that the uniform motion of bodies in straight lines, unless acted on by some force, had been established by Galileo. The regular revolutions of planetary bodies in elliptical orbits, Kepler explained by supposing that each planet was the seat of an intelli-

gent being—a ruling spirit, whose office it was to steer the planet in its course. Descartes found it possible to dispense with Kepler's genii by assuming that the heavenly bodies are carried round in vortices—that is, in a sort of whirlwind. Newton's surmise was, when he had obtained correct data, soon verified by his calculation from the known effects at the surface of the earth, and the theory of the vortices was swept away for ever by the grand conception of universal gravitation."

"I cannot help being struck," observed the vicar, "with the looseness, if I may so term it, with which men of science appear to hold its doctrines, and the readiness with which they all with one consent can surrender even an old, and perhaps universally accepted theory, in favour of another which may be unsanctioned by the authority of illustrious names, and without the support of traditional veneration."

"That is," replied Mr. Seymour, "because the appeal lies directly to the truths of nature. When a theory has been found inconsistent with facts, or unnecessary, it is at once discarded. Even gravitation itself, or the atomic theory, would have to yield, if a principle should be discovered which embraced the phenomena within some wider range of facts. But in all such advances science never loses her hold upon facts once established, the theories being but the means of gathering them up for a firmer grasp."

Louisa here remarked that she was puzzled by what her father had said about every piece of matter attracting other matter, because she thought that bodies should show some signs of this attraction, "and," she said, "move towards and cling to each other, just as pieces of iron do to a magnet; whereas I have never noticed any such tendency, and it would surely show itself if it exists in all bodies."

"The attraction you speak of can be shown to exist between the bodies at the earth's surface, but its power is much too small to be observed except in delicate experiments with special apparatus. I will explain to you how this has been proved."

Mr. Seymour took out his pocket-book, and on a blank page he sketched the diagram (Fig. 43), which is shown in the annexed figure.

"Suppose that one side of a lofty detached mountain formed such a precipice as I have here represented, and that a plumb-line could be suspended in this way. You all know, I presume,

that a plumb-line usually hangs vertically, as shown by the dotted line; yet in the case I have supposed, the weight would, by the attraction of the matter of the mountain, be drawn towards it; and instead of being under the point of suspension as at A, it would be nearer the mountain, as at B. I have, of course, exaggerated the amount of the deflection; but an experiment on this principle was conducted by Maskelyne the astronomer, on a mountain in Scotland called Shehallion, with perfect success. But the attraction exercised by large masses of lead on bullets supported on the extremity of a delicately suspended rod, has been directly measured by Cavendish; and others have since repeated such experiments, but always with results completely confirmatory of Newton's statement of the law of gravitation, namely, *every particle of matter in the universe attracts every other particle, with a force whose direction is that of the line joining the two, and whose magnitude is directly proportional to their masses, and inversely proportional to the square of the distance between them.*

Fig. 43.

"Leaving this statement to be considered more in detail hereafter, I must tell you that Newton demonstrated that one consequence of it, or the direction taken by falling bodies, should be towards the centre of the earth, *as if* the attractive force which is really exercised by each particle resided there. I hope you will not make the mistake of supposing that the force is actually exercised by the centre only. Remember that every particle of the earth attracts every other particle in the earth and in the heavens directly towards *it*, and the total result of these individual attractions is the same AS IF a single force were acting from the centre. The fact of bodies falling towards the centre of the earth was known before Newton's time. Here let me impress this fact upon you," continued Mr. Seymour, again resorting to his pocket-book, in which he made a diagram like that in Fig. 44, "by reminding you that if the opposite walls of a room could be built truly upright, they would not in strictness

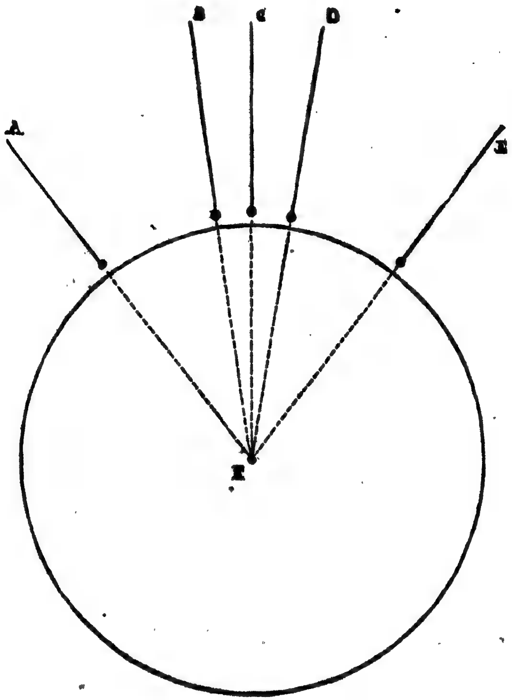


Fig. 44.

be parallel. You see, I have drawn the circle to represent the earth, of which F is the centre, and the lines, A B C D and E, are plumb-lines, each of which points to the centre, F, as if the attraction of the whole lay there, and therefore there will necessarily be an angle, however small, between the direction of two plumb-lines, even when they are close together. Now, as you know the *direction* in which the earth draws a falling body, we ought next to consider the intensity with which the gravitating force acts at the surface of the earth. I hope, Tom, you have not forgotten what I explained yesterday about the manner in which different forces may be compared?"

"It is by the velocities which they would severally produce by acting on the same body under like circumstances," replied Tom.

"That is quite correct," said Mr. Seymour; "and I think you will at once perceive that if we had some one standard body, the velocity which any given force would impart to that body by acting on it for a defined period of time—say, one second—would be a direct measure of the force. Then, in order to measure the force of gravity, we must find what velocity it will impart to our standard body by acting on it for one second; but I do not at all see how it would be possible to make the actual measurement, as bodies fall to the earth so very fast. The measurement has, however, been made repeatedly and with extraordinary accuracy, although not by directly measuring the speed of a body which has been falling for a second. It has, however, been ascertained that a body falling freely at the poles of the earth will attain in one second a velocity of 32·252 feet. I say *at the poles*, because you will presently learn that the force of gravity varies a little with the locality. Thus in the British Islands it is capable in one second of producing a velocity of only about 32·2 feet, and for our purpose it will be near enough to call it 32 feet."

"This, I suppose, applies only to the standard body of which you have been speaking?" said Tom.

"It applies to that, of course," replied Mr. Seymour; "but it so happens that every body falls to the earth with exactly the same velocity."

"What!" cried Louisa, "can it be that a heavy weight falls no faster than a light one? that a large lump of rock, for instance, would fall no faster than a pebble? I am sure that a piece of lead must be pulled down with more force than a piece of wood of the same size."

"Undoubtedly the pull of the earth is greater on the lead; but, then, it has more work to do. An empty waggon might be dragged along a road by one horse at a certain speed, and you would not increase the speed by the united effort of four horses harnessed to the waggon, if you loaded it in like proportion. But for the present let us be contented with an experiment which will prove that, as a matter of fact, gravity impresses equal velocities on all bodies. This can easily be done without any apparatus, but I have prepared a simple arrangement, which Tom shall now bring from the library table."

It was a long narrow box, or trough, the bottom of which was attached at one side only, by hinges. Holding this box in the

Fig. 45.

way shown in Fig. 45, with a number of balls of different materials, such as wood, iron, brass, earthenware, lead, &c., placed in it, he then requested the party to observe the result when he allowed the balls to fall by withdrawing the support of the finger from the bottom of the box. They saw, as shown in

Fig. 46.

the annexed cut (Fig. 46), the whole of the bodies fall in a line, and all reach the ground at the same time. The experiment was repeated with the box held at different heights, and always with the same result.

Louisa still thought that there were facts at variance with the statement that all bodies fall to the earth with equal velocities, and she said that it would be easy to show it was not true in all cases. "For," she continued, "I have only to drop together,

from the bed-room window, a penny and a piece of paper: if I am not much mistaken, you would find that the coin will strike the earth before the paper has performed half its journey."

"Come," said Mr. Seymour, "I will perform this experiment myself, and endeavour to satisfy the doubts of our young sceptic; but I must first take the opportunity to observe that I am never better pleased than when you attempt to raise difficulties in my way, and I hope you will always express them without reserve."

"Here, then, is a penny piece, and here," said Tom, "is a piece of paper."

"Which," continued Mr. Seymour, "we will cut into a corresponding shape and size." This having been accomplished, he held the coin in one hand and the paper disc in the other, and dropped them at the same instant.

"There! there!" cried Louisa, with an air of triumph; "the coin reached the ground long before the paper."

"I allow," said Mr. Seymour, "that there is a distinct interval in favour of the penny piece." And he proceeded to explain that this arose from the interference of a foreign body—the air—to the resistance of which it was to be attributed; and he desired them to consider the falling body as being under the influence of two opposing forces—gravity, and the air's resistance. Louisa argued that the air could only act on the surface of a body, and as this was equal in both cases—the size of the paper being exactly the same as that of the penny piece—she could not see why the resistance of the air should not also be equal in both cases.

"I admit," said Mr. Seymour, "that the air can only act upon the surface of a falling body, and this is the very reason of the paper falling more slowly, for as the force which moves the paper is much less than that which moves the penny, the former is diminished by the air's resistance in a much higher proportion."

At this explanation Louisa's doubts began to clear off, and they were ultimately dispelled on Mr. Seymour performing a modification of the above experiment in the following manner: He placed the disc of paper in close contact with the upper surface of the coin held horizontally, and, in this position, dropped them from his hand. They both reached the ground at the same instant.

"Are you now satisfied, my dear Louisa?" asked her father. "You perceive that, by placing the paper in contact with the

coin, I screened it from the action of the air, and the result is surely conclusive."

"Many thanks to you, dear papa; I am perfectly satisfied, and shall feel less confident for the future."

Tom was delighted; for, as he said, he could now understand why John's paper parachute descended so deliberately to the ground; he could also explain why feathers, and other light bodies, floated in the air.

"Well, then," said Mr. Seymour, "having settled this point, let us proceed to another question. Since gravity, by acting on a body for one second, impresses upon it a velocity of 32 feet per second, what would happen to the body if the action of gravity could be suddenly withdrawn from it after having operated for a second?"

"It would go on," Tom replied, "if nothing interfered with it, moving for ever at the same speed of 32 feet per second."

"But when a body is falling freely in the air from a considerable height, gravity never ceases to act upon it; and if gravity can give the body the velocity of 32 feet during one second, it can do the same during the next and each succeeding second. And after the end of the first second from rest, gravity continues to act upon the body which has already a downward velocity of 32, and its continued action is shown by its adding another 32 feet to this velocity during the second second, at the end of which the velocity would, therefore, be 64; similarly at the end of the third second the falling body will be moving at the rate of 96 feet per second."

"I see now," said Tom: "it is an instance of the accelerated motion you were speaking of the other day, and the number 32 would be called the *acceleration*, that being the velocity added each second, would it not?"

"Certainly; and for this reason gravity is sometimes called an accelerating force. But such a distinction is quite unnecessary, because every force is accelerating; that is, it continues to increase the velocity of a body as long as it acts on it, unless the increase is opposed by other forces."

"Then," said Louisa, "does every body fall 32 feet in one second, 64 feet in two seconds, and so on?"

"By no means," replied Mr. Seymour: "these numbers are the velocities *at the end* of the time from rest. You must remember that although the velocity at the end of the first second

is 32, the body has *not this velocity throughout* that interval, for at the end of the first half-second its speed is only 16 feet per second, and so on—the velocity increasing in exact proportion to the time from rest; and the increase being thus regular, it happens that the space fallen can easily be reckoned, for it is the same as would be passed through by a body moving uniformly with the mean velocity of the falling body. Thus, at the commencement of the fall, the velocity is 0; at the end, it is 32: the average velocity is the mean between 0 and 32—that is, 16 feet the second. The space passed through during the first second is then 16 feet; in the second second, beginning with a velocity of 32 feet and ending with one of 64 feet, the average is $\frac{64+32}{2}=48$, and the space fallen through during the second second is therefore the same as if the body moved during the second with this uniform velocity—that is, it is 48 feet. Therefore, in two seconds from rest $16+48=64$ feet will be fallen through; or, knowing the velocity at the end of the second second to be 64, we calculate the average velocity during the two seconds to be $\frac{0+63}{2}=32$; and as the body has been falling for two seconds, we may conclude it has fallen through $32\times2=64$ feet. I have written for you in this table the velocities and spaces for six seconds:

FALLING BODIES.

Times in Seconds from rest.	Velocities at ends of times.	Spaces fallen during the whole time from rest.
	$32\times1=32$	$\frac{32}{2}\times1=16\times1^2=16$
2	$32\times2=64$	$\frac{64}{2}\times2=16\times2^2=64$
3	$32\times3=96$	$\frac{96}{2}\times3=16\times3^2=144$
4	$32\times4=128$	$\frac{128}{2}\times4=16\times4^2=256$
5	$32\times5=160$	$\frac{160}{2}\times5=16\times5^2=400$
6	$32\times6=192$	$\frac{192}{2}\times6=16\times6^2=576$

"You see that to find what space a body has fallen through, it is only necessary to multiply the square of the number of seconds from rest by 16—or, in other words, to multiply 16 by the number of seconds twice. So, by observing the number of seconds which a stone requires to descend from any height, we can discover the altitude, or depth, of the place in question."

Louisa and Fanny, who had been attentively listening to their father's explanation, interchanged a smile of satisfaction, and, pulling Tom towards them, whispered something which was inaudible to the rest of the party.

"Come, now," exclaimed Mr. Seymour, "I perceive by your looks that you have something to ask of me: is Louisa sceptical again?"

"Oh dear, no!" replied Tom; "Louisa merely observed that we might thus be enabled to find out the depth of the village well, about which we have all been very curious; for the gardener has told us that it is the deepest in the kingdom, and that it was dug more than a hundred years ago."

Mr. Seymour did not believe that it was the deepest in the kingdom, although he believed that its depth was considerable; and he said that if Mr. Goodenough had no objection, they should walk to it, and make the proposed experiment.

"Objection, my dear Mr. Seymour! when do I ever object to afford pleasure to my little playmates, provided its indulgence be harmless? Let us proceed at once, and on our return I hope you will favour me with a visit at the vicarage; I have some antiquities which I am anxious to exhibit to yourself and Mrs. Seymour."

Tom and Rosa each took the vicar's hand, and Mr. and Mrs. Seymour followed with Louisa and Fanny. The village well was about half a mile distant; the road to it led through a delightful shady lane, at the top of which stood the vicarage-house. Mr. and Mrs. Seymour and her daughters had lingered in their way to collect botanical specimens, and when they had come up to Tom and the vicar, they found them seated on the trunk of a newly-felled oak in deep discourse.

"What interests you, Tom?" said Mr. Seymour, who perceived by the inquiring and animated countenance of the boy that his attention had been excited by some occurrence.

"I have been watching the woodman," said Tom, "and have been astonished to observe that the sound of his hatchet was not heard until some time after he had given the stroke."

"And has not Mr. Goodenough explained to you the reason of it?" asked Mr. Seymour.

"He has," replied Tom; "and he reminds me that it is owing to sound travelling so much slower than light."

"You are quite right; and as we are upon an expedition for the purpose of measuring depths, it may not be amiss to inform you that this fact furnishes another method of calculating distances."

The party seated themselves upon the oak, and Mr. Seymour proceeded:

"The stroke of the axe is seen at the moment the woodman makes it, on account of the immense velocity with which light travels; but the noise of the blow does not reach the ear until some time has elapsed, the period varying, of course, in proportion to the distance, because sound moves only at the rate of 1,142 feet in a second, or about 13 miles in a minute; so that you perceive, by observing the interval between the fall of the hatchet and the sound produced by it, we can ascertain the distance of the object."

Mr. Seymour fixed his eye attentively on the woodman, and, after a short pause, declared that he was about a quarter of a mile distant.

"Why, how could you discover that?" cried Louisa; "you had not any watch in your hand."

"But," said Mr. Seymour, "you might have perceived that I placed my finger on my wrist, and as my pulse beats about 70 strokes in a minute, I was able to form a tolerable estimate of the interval, although I confess that it is a very rough experiment, but sufficiently accurate for the purpose of illustration. In the same manner we can readily ascertain the distance of a thunder-cloud, or that of a vessel at sea firing a cannon. If we do not hear the thunder till half a minute after we see the lightning, we are to conclude the cloud to be at the distance of six miles and a half. But let us proceed to the well."

After a walk of a few minutes, the party reached the place of their destination. On their arrival, Mr. Seymour inquired who would count the time.

"Be that my office," said Mr. Goodenough, as he extracted a large silver timepiece from the deep abyss of his watch-pocket; "and let Tom," continued he, "find a pebble."

"Here is one," cried Louisa.

"Very well; now, then," asked Mr. Seymour, "how will you proceed?"

"I shall drop the stone," replied Tom, "into the well, and observe how many seconds it will be before it touches the water."

"But you have not yet informed me how you propose to ascertain the moment at which the stone reaches the water."

"By the sound, to be sure, papa; and you will find that a very loud one will be produced."

"If the depth of the well be considerable, such an expedient will not answer the purpose, since, in that case, there must necessarily be a perceptible interval between the fall of the stone and the sound produced by it, which, unless taken into account, will vitiate the result."

Tom observed that he had not contemplated that difficulty, and was unable to propose any remedy for it. His father told him that he must look at the surface of the water, and mark the moment it was disturbed by the contact of the stone.

"Now, Mr. Goodenough," exclaimed Mr. Seymour, "are you ready to count the seconds?"

"Quite ready."

"Then drop the stone."

"One—two—three—four——"

"There," said Tom, "it touched the water."

"*Facilis descensus Averni!*" exclaimed the vicar; "the stone descended in exactly four seconds."

"Now, my boy, make your calculation."

Mr. Seymour furnished pencil and paper, and Tom quickly completed the calculation, and announced the result.

"Two hundred and fifty-six feet," cried he, "is the depth of the well."

A shout of delight from the whole juvenile party announced the satisfaction which they felt at the success of their experiment. Louisa observed that she could not distinguish any interval between the actual contact of the stone with the water, and the sound which it produced.

"At so small a distance as two hundred and fifty-six feet," said her father, "the interval could not have exceeded in duration the fourth part of a second, and it was consequently imperceptible: we might, therefore, in the present instance, have accepted the sound as a signal of the stone's arrival at the water without prejudice to the result of the experiment."

Mr. Seymour here said that though this experiment would

perhaps serve to impress upon their minds the law of falling bodies, it could not afford anything more than a rough estimate of a depth or height. "For," said he, "the measurement of the time is not sufficiently accurate, since at the depth of the well, for instance, a difference of one-fifth of a second would correspond with about 26 feet of depth. But even if we could estimate the time correctly, the resistance of the air introduces another cause of error. Thus it has been found that a stone allowed to fall from the cupola of St. Paul's Cathedral occupied $4\frac{1}{2}$ seconds in its descent; and if we square this number and multiply by 16·1, a height of 326 feet is indicated; whereas the actual height is only 272 feet, which would have been passed over in a little more than $4\frac{1}{10}$ seconds, had there been no obstacle."

"Not many years ago," said the vicar, "if people had been seen dropping pebbles into the well, as we have been doing to-day, the villagers would have at once concluded they were engaged in fortune-telling; for there used to be a foolish superstition attached to this—and perhaps to other wells in the neighbourhood of remote villages—that by dropping pebbles into it, and observing whether they produce a loud or only a slight sound, and noticing the number of times they rebound from the sides before they reach the bottom, and other absurd distinctions, a person could predict whether good or evil awaited him. Of course, nobody believes in such things now-a-days, when many run to and fro, and knowledge has been increased—*tempora mutantur*——"

"Why, vicar," interrupted Mr. Seymour, "I verily believe that you half regret the old superstitions because they are old, and seem to us picturesque and romantic. But I take it that table-turning and spirit-rapping will be looked upon, after a few hundred years, as some of the picturesque beliefs of the people of the nineteenth century; for remoteness of time lends the same enchantment to the past, that distance in space imparts to the mountain."

Mr. Goodenough forbore to enter upon any further discussion of this topic, but remarked that he thought his young friends and playmates had received for that day as much philosophy as they could well carry without fatigue, and he suggested that the party should now accompany him to the vicarage; to which proposal they readily assented.

CHAPTER XII.

Pleased again by toys which childhood please ;
As, books of fables, graced with print of wood,
Or else the jingling of a rusty medal,
Or the rare melody of some old ditty
That first was sung to please King Pepin's cradle.

MR. GOODENOUGH's antiquated residence, mantled in ivy and shaded by cypress, stood on the confines of the churchyard, from which his grounds were merely separated by a dwarf hedge of sweetbriar and roses ; so that the vicar might be said to reside amidst the graves of his departed parishioners, and the turf-clad heaps evinced the influence of his fostering care by a grateful return of primroses and violets.

Around the house the reverend antiquary had arranged several precious relics, which were too cumbrous for admission within its walls : amongst these was an ancient cross, raised upon a platform on three steps, which, from the worn appearance of

the stones, had evidently been impressed with the foot of many a wandering pilgrim.

Annette, the vicar's trusty servant, had watched the approach of the squire and his family, and, anticipating the honour of a passing visit, was busily engaged in removing the checked covers from the cumbrous oaken chairs when the party entered the study.

"Why, papa," exclaimed Tom, as he cast his eyes around the study, "all these curiosities have been put up since I went to school."

"The boy is right," said the vicar; "I have only just completed their arrangement, and I believe," continued he, addressing himself to Mr. Seymour, "that there are several rich morsels of antiquity which you have not yet seen. But I first propose to introduce my young friends to the wonders of my magic gallery, wherein they may converse with the spirits of departed emperors, heroes, patriots, sages, and beauties; contemplate, at their leisure, the countenances of the Alexanders, Cæsars, Pompeys, and Trajans; behold a legion of allegorical and airy beings, who have here, for the first time, assumed appropriate and substantial forms; examine the models of ancient temples and triumphal arches, which, although coeval with the edifices they represent, are as perfect as at the first moment of their construction, while the originals have long since crumbled into dust. They shall also see volumes of history condensed into a space of a few inches, and read the substance of a hundred pages at a single glance."

So saying, the antiquary took a key of pigmy dimensions from the pocket of his waistcoat, and proceeded to a cumbrous ebony cabinet which stood in a deep recess, and displayed an antique structure, and curiously carved allegorical devices, in strict unison with that air of mystery with which the vicar had thought proper to invest its contents. It was supported by gigantic eagles' claws; its keyhole was surrounded by hissing snakes; while the head of Cerberus, which constituted the handle, appeared as if placed to guard the entrance. The children were upon the tiptoe of expectation and impatience—the lock yielded, and the doors flew open.

"And so," exclaimed Tom, "this fine magic gallery turns out to be nothing more than a box full of old coins!"

"Hush!" cried the vicar; "you talk like one not initiated

in the mysteries of enchantment: have you not read, that under its spells the meanest objects have assumed forms of splendour and magnificence? In like manner, then, may treasures of the greatest value appear to ordinary eyes as mean and worthless. This cabinet," playfully continued Mr. Goodenough, "is under the influence of a potent enchantress: by the touch of her wand it would become irradiated as with celestial light, and these rusty coins would be transformed into all those various objects of interest and delight which I had promised to show you."

Tom and Louisa looked at the coins, then at the vicar, and afterwards at Mr. Seymour, to whom they cast an inquiring glance.

"Then pray," exclaimed Tom, "wave this mighty wand of your enchantress, and fulfil your promise."

"The enchantress," replied the vicar, "is not disposed to grant her favours to those by whom she has not been propitiated."

"And what mystic rite does she require?" said Louisa.

"The perusal of sundry cabalistic volumes, and the consumption of many a midnight lamp at her altar," replied the vicar.

"Do you not comprehend the allegory?" said Mr. Seymour. "The enchanted gallery is no other than a collection of antique medals; the potent enchantress is Erudition, or that classical learning without which they appear of less value than so many rusty halfpence."

"You are right," cried Mr. Goodenough; "the poetical import of a device can be alone felt and appreciated by those who are acquainted with the classical subjects to which it alludes."

"The ancients," said Louisa, "seem to have had a very great variety of coins."

"You must not suppose," replied the vicar, "that these all had ever any currency as coins."

"If they were not used as money," observed Louisa, "for what purpose could they have been coined?"

"To perpetuate the memory of great actions; and, faithful to its charge of fame, the medal has transmitted events, the history of which must otherwise have long since perished. Nay, more," exclaimed the vicar, his voice rising as he became warmed by his subject, "often when the lamp of history has been extinguished, the medallist has collected from the ashes of antiquity

sparks which have rekindled the flame. You perceive, therefore, that such collections are of the highest importance, and if your papa will allow you to pass a morning in their examination, I shall easily bring you to admit that I have not exaggerated the wonders of my magic gallery. I will convince you that it contains a series of original miniature portraits of the greatest heroes of antiquity; a compendious chart of history, chronology, and heathen mythology; a system of classic architecture; and an accurate commentary upon the more celebrated poems of Greece and Rome. Ay, and I will show you a faithful resemblance of the very ship that carried Æneas to Italy, and of the lofty poop from which the luckless Palinurus fell into the ocean."

Mr. Goodenough then favoured Mr. and Mrs. Seymour with a sight of some of those rarer medals which he considered as constituting the gems of his collection.

"You do not mean to say," exclaimed Tom, as he seized a small coin, "that this little *brass* piece is of more value than the large coin of gold that lies next to it?"

"Mercy upon us!" cried the vicar, in a tone of agony, "how the boy handles it! Restore it to its place!—gently—gently! That 'little brass piece,' as you call it, although it might not have been worth a penny fifteen hundred years ago, is now valued at more than a hundred guineas."

Early the next morning the youthful group again assembled in the library, eager to learn more about forces and motions. Mr. Seymour began by reminding them of that part of the statement concerning the law of gravitation which asserts that the force with which two particles attract each other is inversely proportional to the square of the distance between; and he pointed out that the diminution of force took place in precisely the same way as the decrease in the intensity of light, according to the distance from the source of light.

"As a consequence," he said, "of this law, if a stone could be let fall from a height of 4,000 miles above the surface of the earth, the stone, instead of having after falling for one second a velocity of 32, would have a velocity of only 8 feet per second. For, in the case of a body like a pebble, insignificant as compared to the earth, the attraction of the latter upon it practically acts as if concentrated at the earth's centre. Assuming the radius of the earth to be 4,000 miles, the body 8,000 miles from

it would be attracted not with half, but with only one-fourth of the force exercised at the earth's surface."

Tom here remarked that as the attraction thus diminishes with the distance from the earth's centre, a stone dropped from the top of St. Paul's Cathedral would begin to fall with a smaller acceleration than one which was dropped only from the top of a house.

"No doubt that is the case," replied Mr. Seymour; "but the amount of the difference is so very small, that it may be entirely neglected for all ordinary purposes; for a few hundred feet is very small in comparison with 4,000 miles. But it is true that at considerable elevations, as on lofty mountains, an appreciable difference shows itself, and in certain scientific observations must be taken into account. Thus, a weight of 500 pounds would, at the top of a mountain four miles high, be found about one pound lighter."

"But," objected Louisa, "that could not be proved by anything put into scales, for the decrease would affect both the material weighed and the weights themselves."

"That remark is quite just," replied Mr. Seymour; "but there would be no difficulty whatever about the matter, for a *spring balance* would at once show the difference. But now, Tom, to show that you quite understand this subject, please calculate for us what would be the reading of a spring balance if we could take one supporting our weight of 500 pounds to the distance of the moon, which is about 240,000 miles from the earth—that is, about 60 times the earth's radius."

Tom at once said the weight would be diminished in the same proportion as the square of 60 is greater than the square of 1; and he performed the calculation thus:

$$\frac{\text{Required Weight.}}{500} = \frac{1^2}{60^2} = \frac{1}{3{,}600}$$

$$\therefore \text{ Required Weight} = \frac{500}{3{,}600} = 0{\cdot}14 \text{ lbs.}$$

—and announced that the result showed that the spring balance would therefore mark somewhat less than 2¼ ounces.

"What an extraordinary decrease!" cried Louisa; "it hardly seems credible that nine 56 lb. weights could, under any circumstances, be attached to a spring balance, and only bring its

index down to 2¼ ounces. I suppose that, on the other hand, if one were to take a spring balance with a weight down into a deep coal-mine, the weight would get heavier, because it would be nearer to the centre of the earth; and if it could be taken down to half the distance from the centre, it would be four times as heavy, and so on."

"This time your conclusions are not correct," said Mr. Seymour. "You must not forget that the attractive force does not really exist at the centre only, but is *(cæteris paribus)* uniformly operative throughout the mass; and therefore, if you will consider a little, you will see that a particle, say 2,000 miles below the earth's surface, must be attracted *upwards* by the matter above it, and it is therefore under very different conditions from a particle outside of the earth. Now, it admits of easy mathematical demonstration, that if the earth's substance were uniform throughout, the force drawing bodies towards the centre would diminish in exact proportion to the distance from the centre, where it would be absolutely nothing."

"In that case bodies at the very centre," exclaimed Tom, "would have absolutely no weight. I always supposed till now that they would be pulled with greater and greater force as they came nearer to the centre, and that, when there, their weight would be enormous."

"That notion arises from your thinking of the earth's centre as the real and only point of gravitative attraction. But the force of gravity does not, as a matter of fact, diminish according to the simple law I have pointed out, for the matter of the earth is not uniform throughout its mass, being, so to speak, packed closer as we descend from the surface. For this reason gravity continues to increase below the surface, but not by the law of inverse squares, attaining its greatest intensity at a depth equal to a sixth of the radius, where the acceleration would not exceed 34½ feet. Below this the value declines to the centre, and at a depth of about one-third of the radius it is equal to that at the surface."

"Thank you, dear papa," said Louisa, "for the pains you have taken in explaining this subject to us."

"Now we can proceed to another law of motion and force, of which I can show you some simple illustrations."

Mr. Seymour then arranged a number of billiard-balls close to the edge of a table, in the manner shown in the annexed figure,

which represents the table as viewed from above. A B C D are the balls, E F the edge of the table. Holding a piece of wood like H G in his hand at G, Mr. Seymour moved it rapidly by a horizontal sweep as if it turned on a centre at G, so that all the balls were simultaneously sent over the edge of the table; but as the parts of the stick farthest from the centre at G moved with greater quickness, the balls D C and E were propelled from the table with different velocities, and came to the ground at different distances from the table, D being projected into the room the greatest distance, while A, which was already on the very edge of the table and merely touched by the slowest-moving part of the stick, simply dropped off and fell vertically downwards. The children were somewhat surprised to find—and it

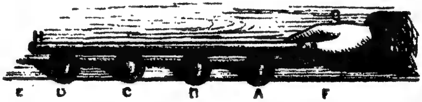


Fig. 47.

was this the experiment was designed to show—that all the balls reached the ground at the same instant.

"I should have been confident," said Tom, "that the ball thrown farthest took the most time in its journey, if I had seen them thrown off separately."

"But now, you see, all these balls, though moving with different horizontal velocities, are acted on by gravity in exactly the same manner. The downward force, then, produces on each the same effect as if the ball had no horizontal motion. This experiment illustrates a fact which we shall find to be invariable; for it is no other than Newton's second law of motion, namely, that

"*Whenever a force acts on a body, it produces upon it exactly the same change of motion in its own direction, whether the body be originally at rest, or in motion in any direction or with any velocity—whether it be at the same time acted on by other forces or not.*

"It will be very instructive now to perform with me another experiment, for which I have obtained this large upright board."

This was a large board, five or six feet square, supported as

shown in Fig. 48. Attached to the upper angle of the board there was a piece of wood, W, cut out in the form of the quarter of a circle, and hollowed out so as to form a curved groove. Mr. Seymour then having obtained a marble from John, placed it as at M; and when the party had arranged themselves in front of the board, he let the marble drop, and asked them to

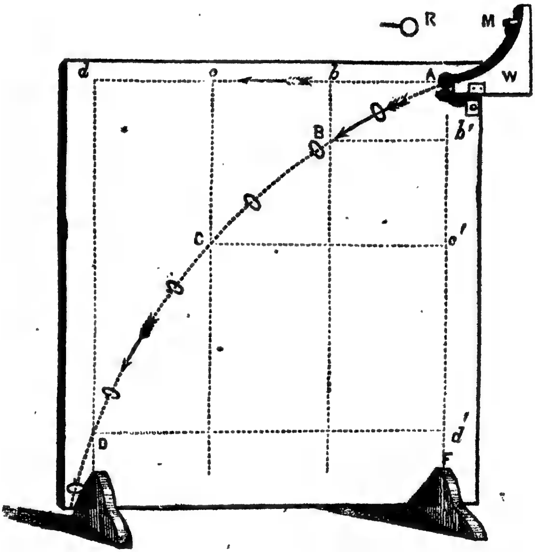


Fig. 48.

observe the path it described, in order that they might be able to fasten into the board four or five rings, like R, so that when the marble was dropped from A, it should pass in succession through the centres of the rings, which were, however, not of much greater diameter than the marble. Tom and the rest were much delighted at being set to make these adjustments, it was so much like a game. It required, however, several trials before the rings were so fixed that the marble passed through them all, and it was found necessary to place a stop at M, so that the marble should always start from the same place. When this had been accomplished, Mr. Seymour requested Tom to define

more completely the course of the marble by means of a chalk-mark on the board. This Tom did, and by making corrections here and there, succeeded at length in drawing the curve represented by A B C D in our figure, so that the falling marble appeared to those who stood in front of the board to follow in its fall the path thus traced out; and he and the rest were not a little gratified by the success of their efforts.

"Now, Tom, I ask you to tell me how the marble would behave after leaving the curved trough here at A, if gravity, at the instant of its leaving, ceased to act upon it."

Tom replied, "The velocity it would have acquired in falling down the trough, would carry it with uniform velocity in a horizontal direction along this line, A *d*."

"Quite right. It would take a certain time to reach, say, the point *d*: can you show me exactly where it would be at the end of each third part of that interval of time?"

Tom divided the line A *d* into three equal parts, as at *b* and *c*, and indicated the points, *b*, *c*, and *d*, as the required positions. Mr. Seymour then asked him to draw from each of these points vertical lines; and this having been done, it was explained that the marble would retain its horizontal velocity unaffected by the action of gravity, or, in other words, its actual velocity in the curve A B C D would, when *resolved* horizontally, be uniform; and that therefore the marble must pass the points B, C, and D, at equal successive intervals of time after leaving A. Mr. Seymour then drew the line A F, and from B, C, and D, the horizontal lines B b', C c', D d'—remarking that his audience now, no doubt, understood that b', c', and d' would be the positions the marble would have had in the same equal intervals of time, had it simply fallen vertically from A. Tom said he quite understood this, and that he should like to measure the distances A b', A c', and A d', to see that they agreed with the law of falling bodies. He accordingly did so, and found the following distances: A b'=6 inches; A c'=23; A d'=51.

"I perceive," said he, "these numbers are not exactly proportional to the squares of the times; for if the body fall 6 inches in the first interval, it ought at the end of the second to be $6\times2^2=24$, and at the end of the third $6\times3^2=54$ inches below the point it started from."

"You must remember," said Mr. Seymour, "you have not taken into account a third force acting on the falling body,

namely, the resistance of the air, which increases at a much greater rate than the velocity itself, and therefore would act more powerfully on the more rapid downward velocity. I think our experiment is a very good illustration of the fact that the action of a force on a body is independent of any motion the body may possess. The paths of projectiles, such as those described by an arrow in its flight, or by a stone thrown into the air, or by the shot fired from a cannon, are all curves of the same kind as this you have drawn on the board; for no sooner does the arrow leave the bow than gravity begins to act upon

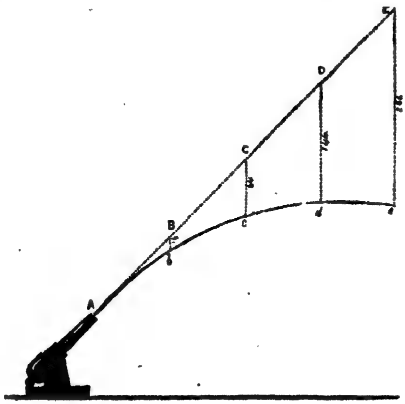


Fig. 49.

it, and from that instant it is virtually falling downward with an acceleration of 32 feet per second, even though it may actually be rising upwards."

"Falling while it is rising!" cried Louisa. "Now I *am* quite at a loss to understand."

"Here is a diagram (Fig. 49) which will help you," said Mr. Seymour. "Let a shot be fired from A in the direction A E. You will admit that if gravity did not act upon it, it would pursue its course in a straight line with a uniform velocity; so that at the end of each second, say, it would be at the equidistant points B, C, D, E. During the first second gravity alone would make it fall 16 feet; but in reality both these motions occur simulta-

neously, and the actual position of the shot at the end of the first second is the result of the joint action. We arrive at this position if we suppose that for one second the original impulse alone is active, with the effect of bringing the shot to B, and then that for one second gravity alone acts on the otherwise stationary body with the effect of bringing it to *b*, 16 feet below B. Similarly the position of the shot two seconds after leaving the gun will be that of a body which has been falling for two seconds from C; and at the end of the third second the shot will be 64 feet below D, and so on."

"This, I think," said Louisa, "I perfectly understand."

"Well, then, suppose the shot were fired at a greater angle, that is, with the gun directed more upwards, that circumstance would not, in your opinion, affect the validity of my explanation?"

"Not in the least, papa."

"Not if the angle with the horizon were very great, say 85°, or 89°, or why not 90°? when the shot would of course be projected vertically upwards. If the explanation is good for 89°, why is it not for 90°?"

"I see now that gravity must act on a body projected vertically upwards, just in the same way as on the marble in our experiment. But are not the curved paths of projectiles called *parabolas*?"

"It is usually asserted," replied Mr. Seymour, "that projectiles would move in parabolic curves but for the resistance of the air; and this is true if we regard the direction of gravity as acting in parallel lines throughout the spaces passed over. But as gravity is directed towards the centre of the earth, the path of the projectile would in strictness be a portion of an ellipse. You may now understand that if a body be projected upwards, gravity destroys 32 feet of that velocity every second, and that, therefore, if the body had an upward velocity of 32 feet per second to begin with, this would be gradually destroyed, so that at the end of one second the body would cease to move, and gravity would continue its action by bringing it down, and in another second the body would be moving downwards with the same velocity it began to rise with. If the body had an initial upward velocity of 96 feet per second, its upward velocity at the end of each second would be

At end of 1st second............... $96-(32\times 1)=64$
" 2nd " .... $96-(32\times 2)=32$
" 3rd " .... $96-(32\times 3)=0$;

that is, it would rise for 3 seconds, and at the instant it changed its direction the velocity would be 0. It then begins its descent, gaining downward velocity with time at the same rate it lost upward velocity, and passes each point in its descent with the same velocity it possessed in its ascent. If a body be projected in any other direction than the vertical, the very same thing is true of the velocities when resolved vertically. Before I quit this subject, I would just observe that, when we come to the consideration of the bow and arrow, Tom will, by the application of the law I have endeavoured to expound, be enabled to ascertain the altitude to which his arrow may ascend, with the same facility as he discovered the depth of the well; for, since the times of ascent and descent are equal, he has only to determine the number of seconds which intervene between the instant at which the arrow quits the bow to that at which it falls to the ground, and halving them, to make the usual calculation.

"There is another simple experiment which I wish Tom and Louisa to perform, as it shows the effect of two forces acting simultaneously on the same body. Do you each take a cue, and at a signal I will give, push this billiard-ball at the same instant in different directions: you see, it takes a diagonal direction." (See Fig. 41, page 136.)

Mr. Seymour now produced a little toy spring pistol, attached to a piece of wood in such a manner that when the block of wood was placed on the billiard-table, the release of the spring of the gun pushed out of the barrel a stick which acted like a cue, in propelling a ball along the table. He explained that his object was to apply an unvarying force to the balls. He then asked them to observe the velocity with which an *ivory* billiard-ball was propelled by the discharge of the spring; and then, placing on the table a solid *brass* ball of the same size, he repeated the experiment with the brass ball, which rolled away from the little apparatus with a slowness that appeared quite majestic as compared with the more lively movement of the ivory ball.

"Now," said he, "we have here applied exactly the same force to these balls, which are of the same size, and we see that a far higher velocity has been imparted to the ivory ball than to the brass one. Can any one give a reason for this difference?"

"It is because the brass ball is the heavier," cried several voices simultaneously.

"I admit," said Mr. Seymour, "that the brass ball *is* much heavier than the ivory one; but I fail to perceive that the difference is thus explained, for gravity has not been opposed to the movement of these balls: they have remained on the same level; we have not used any part of the force of the spring to raise either of them against the force of gravity."

"It must, then, be," said Tom, "because the weight of the brass ball causes it to move along the table with a greater amount of friction—it sinks, as it were, into the cloth more than the ivory ball does, and this introduces a greater retarding force."

"That is very well advanced," replied Mr. Seymour, "and there is no doubt that the retarding force you have pointed out is actually in operation in our experiment; but its amount is much too small to account for the very marked difference of speed which you have just witnessed. I must tell you that if we could transport ourselves and this table to the moon's distance from the earth, where your calculation showed that the balls would have only $\frac{1}{3600}$th part of their present weight, we should find, on repeating our experiments there, precisely the same result: the balls would move along the table with the same respective velocities as in this room. We might even suppose our table carried to still greater distances, and the results of our experiments would, I must assure you, remain unchanged. Thus weight might be actually abolished, and we should still find the brass ball impelled much more slowly than the ivory one by the same force. The conditions of our experiment *practically* exclude the action of gravity except in the accidental circumstance of the increased friction which Tom has pointed out, and this is quite inadequate to account for the difference of velocities. We cannot, therefore, think that the brass ball moves slower because gravity causes it to press on the table more than the ivory ball; yet that is the only effect of the difference of *weight* in the present experiment."

Tom and Louisa both admitted that it could not be the different downward pulls of the earth on the two balls which caused them to take on such different velocities from the same force; and they begged their father to inform them to what this effect must be attributed. Mr. Seymour said he was now presenting them with ideas which would be altogether new, and therefore they must not be disheartened if they found, as no doubt they would, that such things must be reflected upon

before the ideas became their own. He remarked also that, judging from the confused manner in which this point has been treated of in some popular books of science, it would appear to be more difficult than the views they had already discussed. He asked them to exclude from their minds all notions about weight, by supposing that they were somewhere far away from the earth.

"In the first place," he continued, "if the same force, applied *for the same length of time and in the same way* to two different bodies, produces the same velocity in each, these bodies are said to have the *same mass;* or, bodies which, under the influence of equal forces, receive equal accelerations, are of equal mass. The masses of the ivory and of the brass ball are, as you have just seen, unequal. Now, it is known by experiment that if I were to divide this brass ball into two equal parts, and cast each of these into a globular form, I should find, on submitting each of these smaller balls to the action of our little spring, that they acquired the same velocity—as, indeed, it could not happen otherwise, seeing that the two smaller balls would exactly resemble each other in every respect. Suppose now one of these smaller balls to be again exactly halved, and the parts again formed without loss into still smaller balls, each of which would have in it one-quarter of the brass of the original ball. Experiments would also show that, when the same force is applied for the same length of time to these different sized balls, the velocities produced would vary inversely as the quantity of brass: the quarter-sized ball, for instance, would gain four times the speed of the original one, the half-sized one would acquire only double. Therefore, the relative masses of these different brass balls, beginning with the smallest, would be said to have to each other the proportions 1, 2, 4. Now, it so happens, and the fact could be learnt only by experiment, that a brass ball one-quarter the size of this large one would be sent across the table by our spring at the same velocity as the ivory billiard-ball; consequently these would be said to have the same mass. But as the largest brass ball has four times the mass of the smallest, so also it has four times the mass of the ivory billiard-ball. In this way, you observe, it would be possible to compare the masses of bodies formed of different kinds of matter. You may see, if you look into the books, that some authors define mass as the *quantity of matter* in a body. I have just explained to you how we may say that an ivory ball has the same mass as

a brass one about a quarter the size; but if I said that the one body has the same *quantity of matter* in it as the other, I should be using words without any real meaning. You would naturally ask how you could measure the quantity of matter. How could any one tell whether or not a given piece of ivory has the same *quantity of matter* in it as a given piece of brass? Those who set out with this definition are obliged to refer to weight: matter in itself is unknowable, much less measurable, by us. But I have shown you that the idea of mass is something quite distinct from that of weight; and therefore it is plainly left for experiment to discover whether the masses of bodies have a definite relation to their weights or not. Now, remembering that the pull of gravity, or weight, is the force which imparts motion to an unsupported body, will you tell me which of these two balls the attraction is more strongly pulling downwards—the brass or the ivory ball?"

"The brass ball, of course," answered Tom and Louisa, simultaneously.

"And if the brass ball is four times as heavy as the ivory ball, it is pulled with four times the force?"

"Certainly, papa."

"Now, see: when I drop these two at the same instant from any height, you perceive that they keep always at the same level in their fall, and reach the ground together. This shows that the greater force acting upon the brass ball is exactly compensated by its greater mass, so that equal velocities are produced; and as the same is true of any bodies whatever—for all fall to the ground with the same acceleration—we must conclude that *the masses of bodies are proportional to their weights.* Therefore the same numbers which express the weights of different bodies might also express their masses. But for certain good reasons, men of science have adopted different units in the two cases. A piece of metal which weighs 32 pounds, has its weight represented by the number 32, because the pound is the standard of weight. But a body weighing 32 pounds is said to have its mass=1. Thence, when we have given the number which expresses the weight of a body, we find, by dividing by 32, the number by which its mass is represented."

CHAPTER XIII.

And levying thus, and with an easy sway,
A tax of profit from his very play,
T' impress a value, not to be erased,
On moments squandered else, and running all to waste.

THE next day Mr. Seymour again assembled the children in the billiard-room. He said that he wished to direct their attention to a fact which they had perhaps never noticed, although it was involved in every action of their lives.

"The fact to which I allude," said he, "is this: that no force can possibly act in one direction only, but, on the contrary, always produces equal effects in two exactly opposite directions. I do not expect you will understand the meaning of this statement until you have seen some obvious cases as illustrations."

Mr. Seymour here directed their notice to a little arrangement which he had prepared, and which is represented in Fig. 50. A was a spiral spring of steel wire which had been a little

compressed, and in that condition it was maintained by a thread passing between its extremities. This was supported arch-like between B the brass ball and C the ivory ball, already spoken of; and in order to accomplish this it was necessary to place on the table a little stop of card-board, which should just suffice to prevent the balls being pushed apart by the weight of the spring, but which they could easily roll over when impelled by the release of the spring. Mr. Seymour placed this little arrangement on the billiard-table, so that the ivory ball was about four times as far from one end of the table as the brass ball was from the other. He released the spring by applying a lighted match to the thread. The balls instantly rolled away from each other in the directions indicated by the arrows, and it was observed that they reached the ends of the table at nearly the same instant.

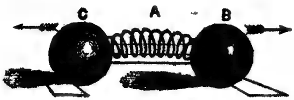


Fig. 50.

"I see," cried Tom, "that this experiment, taken in conjunction with that which we yesterday performed, quite proves that the force of the spring has acted *equally* in opposite directions."

"But," said Louisa, "when John shoots a stick out of his little toy gun, which has a spiral spring in it, the motion is imparted to the stick only."

"You overlook the fact that the gun has not the same freedom to move, being held in the hand; but it nevertheless receives a backward impulse which is exactly equal to the forward impulse given to the stick."

Louisa could not see how this could be; Mr. Seymour therefore had John's gun brought in, and having retained the spring by means of a piece of thread, which could be released by burning as before, he suspended horizontally the toy weapon from the ceiling by a thread at each end, and having inserted a pencil in the barrel for a missile, he discharged the spring by burning its thread, so that the arrangement remained untouched. The recoil of the gun at the instant the pencil was shot forward was now sufficiently obvious, and became still more so when a piece of iron nearly the size of the pencil was substituted, for the gun then moved backward in a very lively manner; indeed, its movement was now more obvious than that of the missile.

"I think," said Mr. Seymour, "you are now willing to admit

the fact of the opposite action of forces. But before we go further I must mention a term which it may be convenient for us to use, namely, *momentum*."

"Pray what may momentum be?" inquired Tom.

"It is simply the product of the number expressing the mass of a body into the number which expresses its velocity, and this product is the measure of a force acting for a given time—one second, for example. You saw yesterday that the same spring imparted to the ivory ball about four times the velocity that it did to the brass ball, and we therefore said the *mass* of this ivory ball is only one-fourth of that of yonder brass ball, which is only saying in other words that the *momentum* was the same in each case. Now, you have seen that the elastic force of the spring I placed *between* the brass and ivory balls produced *equal momenta in opposite directions*, and this statement is true of *all forces whatever;* so that whenever you see a force acting, whether imparting, changing, or destroying the motion of a body, be sure that that same force is producing an equal effect—as measured by momentum—in the diametrically opposite direction. This is the fact which Sir Isaac Newton expressed by saying *Action and Reaction are equal and opposite.*"

"You do not mean to say," exclaimed Tom, "that when I strike a cricket-ball with my bat, it is as if the bat received a backward blow of equal force at the same instant?"

"That is precisely my meaning, and you will at once perceive the truth of this, if you will cease to regard rapidity of motion as the *sole* measure of force. You will admit that the motion of your bat receives some check by striking the ball?"

"Certainly it does," said Tom.

"Then its loss in momentum is that which the ball possessed when it approached your bat, *plus* that which you imparted to it in a changed direction."

"But, papa," said Louisa, "you do not mean to say that if a man strike another on the face, the force of the blow is the same to striker and struck?"

Mr. Seymour answered this question by observing that, if the hand possessed the same degree of feeling as the face, they would both suffer equally under the conflict. "If," continued he, "you strike a glass bottle with an iron hammer, the blow will be received by the hammer and the glass; and it is quite immaterial whether the hammer be moved against the bottle at

rest, or the bottle be moved against the hammer at rest, yet the bottle will be broken, though the hammer be not injured; because the same blow which is sufficient to shiver the glass is not sufficient to break or injure a lump of iron. The operation of this law will be exemplified in every step of our progress. When the marble, as it rolls along, strikes any obstacle, it receives in return a corresponding blow, which will be found to influence its subsequent direction. The peg of the top, as it rubs on the ground, is as much influenced by the friction as if a force were actually applied to it when in a state of rest; and when we consider the forces by which the kite is made to ascend into the air, you will learn, from the same law, the nature of that advantage which you derive from running with it."

Tom said he now remembered several cases in which action and reaction were concerned, as when once he leaped from a boat and alighted in the water, although the distance was one he could easily jump, and he then noticed that his leap had sent the boat away into the water so that he could not reach it again.

Mr. Seymour considered this a very good illustration, but he also mentioned other instances, such as the *rocket*, which is propelled upwards by the reaction between the downrushing gases and the case of the rocket.

Another instance was the "kick" of a fowling-piece at the moment of discharge, when the reaction is sometimes a considerable inconvenience to inexperienced sportsmen. The same thing was seen in the recoil of pieces of ordnance, for which special provision had to be made, by allowing the gun to run back up an inclined plane, or by providing some other means by which the momentum of the piece might harmlessly expend itself.

"But now, Tom," continued Mr. Seymour, "as there is nothing better for testing the accuracy of a person's knowledge of such laws than the application of them to some definite numerical examples, suppose you calculate for us the momentum of the reaction from the discharge of a military rifle which propels a bullet weighing one ounce with the velocity of 1,440 feet per second."

Tom immediately replied that the momentum of the recoil would be $1 \times 1{,}440$, if the ounce were the unit of weight, or $\frac{1}{16} \times 1{,}440 = 90$, if the pound were taken as the standard.

"Now find with what velocity the stock of the rifle would be

driven against the marksman's shoulder, if the weapon were free to move. But you will, of course, require to have the weight of the rifle given, and this we may take as 10 pounds."

"Its momentum," Tom replied, "must, of course, also be 90, and therefore the velocity would be 9, for $9 \times 10 = 90$."

"That is quite right," observed Mr. Seymour, "and, indeed, the law is so simple that you could hardly go wrong, unless you had been guilty of inattention with regard to the units to which the figures were referred."

"I am, however," cried Tom, "much puzzled now to understand how it happens, since the momentum, or force, of the reaction is equal to that of the action, that the discharge of the rifle does not inflict as much damage on the person who fires it, as the bullet would on any one so unfortunate as to encounter it. It is very absurd, but I want to know how is it that the soldier is not shot by the butt of his rifle as effectually as the enemy who is hit by the bullet?"

"Observe, in the first place," said Mr. Seymour, "that it is equality of *momenta* which the law of action and reaction asserts; and when you talked just now about the *force* of the reaction, you had quite another idea in your mind: you were thinking of the destructive effects the moving bodies might be capable of producing."

"And are these not proportional to the momentum?" asked Louisa. "I am sure I saw in a book a calculation of the destructive effects of Vespasian's battering-ram, in order that its power might be compared with that of a cannon-ball; and the estimate was made by simply multiplying together the respective weights and velocities—and, in fact, the case was proposed as an example of momentum."

"I believe," replied her father, "that the erroneous notion you have mentioned is not unfrequently entertained by the writers of books of popular science, and that it may perhaps be found even in formal treatises. But the absurdity to which that idea has led Tom, in the instance of the soldier firing his rifle, bears testimony to its incorrectness. The fact is that the power for destruction which a moving body may possess, is measured by what is termed its *moving energy*, and this, as I shall explain to you another day, is proportional to the weight of the body, and to *the square of its velocity*, jointly. So that if you could double the speed with which a missile strikes its object, the de-

structive energy would be quadrupled, and so on. We are now in a position to make a calculation to show the relative amounts of energy which would be possessed by the rifle-bullet, and by the rifle itself, in virtue of their velocities. We will first calculate the energy of the rifle, which we are supposing to weigh 10 pounds, and to be moving backwards with the velocity of 9 feet per second: the amount would plainly be $10 \times 9^2 = 10 \times 9 \times 9 = 810$. Then, we similarly find the energy of the bullet, thus: $\frac{1}{16} \times 1{,}440^2 = 129{,}600$. Thus, the number for the energy of the bullet is 160 times greater than that which expresses the energy due to the recoil of the weapon. Observe, then, that these numbers, 1 and 160, express the relative amounts of work which are done by the rifle and its bullet respectively before their motions are destroyed—that is, *other things being equal*, the bullet would overcome a resistance 160 times greater than the rifle, or it would overcome an equal resistance through a distance 160 times longer."

"I quite understand now," exclaimed Tom, "that the power which a moving body has of forcing its way through opposing substances is certainly not to be measured by its momentum."

"There is another circumstance we should not overlook, if we are to compare the destructive, or rather penetrating, power of a rifle-bullet with that of the stock of the rifle from which it is fired. We have seen that, *other things being equal*, a bullet projected under the assumed circumstances (which are nearly those that occur in actual practice) possesses, by reason of its superior velocity, 160 times the power of overcoming such resistances as are presented in the penetration of a solid body. Now, observe that the other things are not equal, inasmuch as the bullet possesses this superior power in a much smaller compass. You know how much the penetrating power depends upon the shape: though it is easy to drive a nail into a board in the ordinary way, it would require very great force to make it go in head first. And you observe that the stock of the rifle is terminated in a broad surface, over which the effect of the recoil is distributed; whereas the rifle-bullet is sharply pointed."

The arrival of the hour of luncheon interrupted the conversation on the law of action and reaction; but it was arranged that after the meal some illustrations of the laws of motion should be sought for in certain pastimes of boys and men, which depend entirely upon the operation of these laws. Accordingly when,

after the mid-day meal, Mr. Seymour and the vicar rejoined the children out of doors, Tom was displaying to his sisters many instances of his adroitness and skill in shooting at and hitting marbles.

"Why, Tom!" exclaimed Mr. Seymour, "how came you possessed of such a multitude of marbles?"

"By luck—good luck, papa. I won them all before the holidays; and I can assure you that my schoolfellows acknowledge me as one of the best players at 'ring-taw' in the school. I wonder who invented marbles?" Tom continued.

"That question, my dear, must be addressed to Mr. Goodenough, who, I have no doubt, will readily answer it."

"Not so readily as you may imagine," replied the vicar; "but I will tell you all I know upon the subject. It appears to be a very ancient game; for it is stated by Suetonius, that Augustus, when a youth, spent many hours in the day in playing with little Moorish boys '*cum nucibus*'—that is, *with nuts*, which appear to have been then used in the very way in which you now play with your marbles. In later times, round stones picked out of gravel were introduced for this purpose. The marbles which you now hold in your hand are substitutes of still more modern invention. The best of them are imported from Holland, where, as I have been informed, they are manufactured by grinding fragments of alabaster and of other stones in an iron mill of a peculiar construction, in which there are several partitions furnished with rasps, which turn with great velocity by means of a stream of water; and the stones having thus been rounded, are projected out of different holes for which their sizes may adapt them. Thus manufactured, they are brought down the Rhine, and from thence dispersed throughout Europe. There are, however, as you well know, inferior kinds, which are of home manufacture, and consist of baked clay, or potter's clay glazed."

"Pray why are some kinds of marbles called *taws* and others *alleys?*" asked Tom.

"The former, as you know," the vicar replied, "are dark-coloured, while the latter are valued for the purity of their whiteness. *Taw* is an abbreviation for 'tawny,' a word descriptive of the colour of the marble; while *alley* is abbreviated from 'alabaster,' the stone of which it is composed."

"Now, then," said Mr. Seymour, "for a game: what is it to be, Tom?"

"'Ring-taw' for ever!" cried Tom; "it is the only game of marbles worthy of being played."

"It is really so long since I left school," observed his father, "that I must beg you to refresh my memory, and give me some instructions about this favourite game of yours."

"I will tell you all about it. We must first draw a circle, in which each player is to put a certain number of marbles, to be previously agreed upon; we then make a mark at some distance, which is called the 'offing,' and from which we are to shoot at the marbles in the ring."

"That is all very intelligible," observed his father; "and I suppose the object of the player is to shoot a marble out of the ring, which not only gives him that marble, but entitles him to shoot again at another, and so on, until he misses, or all the marbles are won."

"That is right, papa."

"And a good marksman," observed the vicar, "who has the first shot, may easily win the game, before any other player can gain the opportunity of shooting at a single marble."

"I see that clearly," said Mr. Seymour: "he may strike out a marble from the circle, and then shoot at another, and in this manner traverse the whole ring; I therefore conclude that good players will always demand a large ring, or else there would not be much chance for any one, except for him who played first."

"That is the game; but I must tell you," said Tom, "that if the player should leave his own marble in the ring, he is at once put out; and should it be within a certain distance on the outside, an adversary may shoot at it, and by hitting it, put him also out of the game."

"I believe that I am now a perfect master of the subject," said Mr. Seymour; "what say you, vicar?"

"I understand it; and it appears to me to be capable of some scientific calculation; but the practical results must, of course, differ very widely from the theory, for the unevenness of the ground, and the inaccurate construction of the marble, are circumstances which never can be duly estimated."

"Certainly not," replied Mr. Seymour; "these difficulties even exist at the game of billiards, where the table is smooth and perfectly horizontal; but we do not require perfect accuracy —an approximation to it will be sufficient for the purposes of illustration; we will, therefore, if you please, proceed at once

to the game, and I will endeavour to point out to Tom the nature and direction of the several forces by which each marble will be influenced."

Tom accordingly converted his legs into a pair of compasses, and described, with the toe of his shoe, the necessary circle upon the ground. Each party, by agreement, placed two marbles upon the ring, and it fell to the lot of the vicar to open the campaign. Mr. Goodenough then advanced, and with the assumed air of a true knight-errant, approached the ring, exclaiming with a loud voice, and with a gesture of inexpressible drollery, "I demand gracious leave that I may be delivered of my vow, and forthwith combat in the lists." So saying, he unfurled his red banner, and sounded a trumpet; or in more humble phraseology, he extracted his handkerchief from his pocket, and applying it to his nasal organ, produced a loud and thrilling blast, which frightened every sparrow from its resting-place. After this preliminary ceremonial, he marshalled his limbs into the most appropriate attitude, and thrusting one hand behind the exuberant tail of his coat, he, with the other, shot forth his missile at the largest marble opposite to him. His *taw* faithfully delivered its errand, and inflicted such a blow upon the paunch of its antagonist, that, although nearly twice the size of its assailant, like a true bully, it skulked off, and retreated several feet beyond the lists; but, alas! the little marble of the vicar, unlucky wight! was so stunned by the operation, that it staggered and reeled backwards into the ring, and thus, according to the established law of the field, completed by one act the total defeat of its luckless commander. "Your marble is left in the ring!" exclaimed Tom, with a shout of triumph.

"I see how it happened," said Mr. Seymour: "the vicar struck the marble plump, or 'played a full ball,' as we say at billiards, and the result easily admits of explanation. When one marble impinges on another, their centres continue to approach each other after actual contact between the marbles, until an instant arrives when they have a common velocity. After this, their elasticity, in restoring the original shapes, drives their centres apart again; and in doing so, of course generates momenta equal in opposite directions. The backwards momentum thus imparted diminishes, destroys, or reverses the motion of the striking marble, according to the value of a certain relation amongst the masses and actual elasticities of the bodies."

It was now Mr. Seymour's turn to enter the lists. He carefully applied his knuckles to the ground, and taking aim at a little marble which he had selected as his victim, gallantly shot the missile from his thumb and finger; but, alas! alas! the goddess, whatever may be her name, who presides over this species of tournay, doubtless saw the impending fate of her favourite, and, after the example of Venus, who turned aside the weapon from Æneas, assumed the shape of a small pebble, and thus arrested the fatal course of the marble, and gave it a new direction, which sent it curvetting through the ring, without committing one single act of devastation.

"Bravo! bravo!" exclaimed Tom; "it is now my turn."

The boy, according to the usage of the field, might at once have won the game by striking his father's marble; but he was too magnanimous to take such an advantage, and too eager to display his own skill, to cut the game short by a manœuvre: he had determined to win his laurels by hard fighting and generalship. He accordingly proceeded to strike a ring marble; in effecting which he had, like the vicar, challenged a *gigantic knight* as his antagonist, but instead of striking it *plump*, he struck its upper quarter, so that it was rolled out of the ring, while the striking marble, imparting only a portion of its momentum, continued to move forward after the impact. This course was greeted with the acclamations of Mr. Seymour and the vicar, the latter of whom declared it to have been "nobly run" and gallantly accomplished; and extracting a sixpence from his waistcoat-pocket, exclaimed, after the manner of chivalry, "*Largesse, largesse!* glory to the sons of the brave! glory to the invincible knight of the taw!"

The boy had not only struck the marble out of the ring, but he had, at the same time, contrived to place his own marble in the most favourable position for his future operations; and, indeed, it may be here observed, that in this consists the art of playing the game. It is almost unnecessary to add that Tom won every marble in succession.

The party now proceeded to return to the Lodge.

"I hope," said Mr. Seymour, addressing himself to Mr. Goodenough, who was walking a few paces before him, "that the maiden ladies have not espied their vicar at a game of marbles; if they should, what a chuckling would there be at their next tea party!"

"A fig for the spinsters!" exclaimed the vicar, as he hastily turned round, and arrested the progress of the party by his gesture. "You really speak, Mr. Seymour, as though it were derogatory to my character to descend from the more austere pursuits to the simple but innocent amusements of youth. Let me remind you, sir, that the Persian ambassadors found Agesilaus, the Lacedæmonian monarch, riding on a stick."

"True," replied Mr. Seymour; "and the ambassadors found King Henry IV. playing on the carpet with his children; and it is said that Domitian, after he had possessed himself of the Roman empire, amused himself by catching flies; but these were kings. Now, I admit that philosophers are monarchs, but monarchs are not always philosophers; you must, therefore, produce some less objectionable authority, if you stand in need of such a sanction. Let me see whether I cannot assist you: there was Socrates, who, if tradition speaks truly, was partial to the recreation of riding on a wooden horse, for which his pupil Alcibiades laughed at him."

"I care not who laughs at me," exclaimed the vicar; "I enjoy the amusements of youth, and agree with Dr. Paley, in regarding the pleasure which they are made to afford as a striking instance of the beneficence of the Deity; and should you so far relax as to put into execution your plan of writing a work upon juvenile sports, I hope you will call upon me to compose a eulogy by way of preface."

"I shall not forget your offer, depend upon it."

"Did not Archytas," resumed the vicar—

> "'He who would scan the earth and ocean's bound,
> And tell the countless sands that strew the shore,'

as Horace says,—invent the children's rattle? Toys, my dear sir, have served to unbend the wise, to occupy the idle, to exercise the sedentary, to reform the dissipated——"

"And," interrupted Mr. Seymour, "to instruct the ignorant."

Mr. Seymour, on their return, proceeded to explain the laws of impact, by which the movement of each marble was directed. He observed that the subject embraced two propositions, viz., the direction of the *object* marble, after having been struck, and that of the *striking* marble, after the stroke. He said that if a straight line were drawn between the centres of the striking and object marbles, it would necessarily pass through their point of

contact, and, if continued, would represent the path of the latter after the blow; and the direction of the striking marble would be determined by drawing from its centre, at the moment of collision, a line which would form, with the line joining the centres of the marbles, an angle equal to that between the latter line and the path of the striking marble before impact.

Mr. Seymour now suggested that they should proceed to the billiard-room, as he there wished to exhibit some instances of reflected motion which would illustrate the subject they were considering. The party having proceeded thither, it was explained to them that the skill of the billiard player really consisted in applying the principles which govern the collision of elastic bodies, and the composition and resolution of forces.

"Not that a billiard player," said Mr. Seymour, "consciously applies these principles by any kind of scientific calculation. His skill can be acquired by practice only, and though illustrative of, is not derived from, the laws of mechanics. Nevertheless all the motions of the balls are determined by certain definite mechanical principles, and though the billiard player by long experience learns to avail himself of these principles, he may be, and usually is, quite incapable of expressing or explaining them. We may now, however, consider the scientific principles which determine the motions of the balls, in some simple cases, and first we will take the instance of a ball striking the cushion."

Mr. Seymour here several times propelled one of the billiard-balls obliquely against the cushion, and he pointed out that the ball rebounded at the same angle in the opposite direction. He then sketched the annexed diagram (Fig. 51), and proceeded as follows:

"When I rolled the ball against the cushion, B, in the direction A B, having struck it, it glanced off, making an angle, E B C, in its passage back again, equal to that which it made on its approach. If I draw the perpendicular B D, this fact will be rendered more apparent, and you will perceive that the angle A B D is equal to the angle C B D: the former is termed the *angle of incidence*, the latter the *angle of reflection*; and these angles, remember, are always equal, provided the bodies under experiment be *perfectly elastic*."

"Do you mean to say," asked Tom, "that the more obliquely you roll the ball against the cushion, the more obliquely it will rebound?"

"Exactly—that is my meaning; and see whether you cannot explain the fact, for it depends upon the composition and resolution of forces, a subject which I should hope you will soon thoroughly understand."

Tom pondered for some time over the drawing, and at length

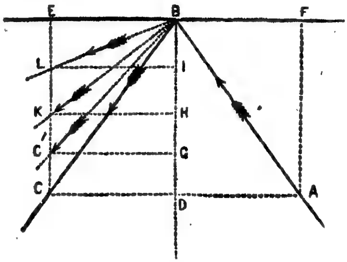


Fig. 51.

observed that there was one difficulty which he could not immediately surmount.

"State your difficulty," said Mr. Seymour.

Tom proceeded to observe that the force acting in the direction A B, might certainly be resolved into two others, viz., one in the direction F B, and another in that of D B; "because," continued he, "these lines are adjacent sides of a parallelogram, of which A B is the diagonal; and I well know that a force may be thus resolved."

"That is all very well explained," replied his father; "pray proceed."

"Now comes the difficulty," continued Tom; "for the force D B will, of course, be destroyed by the resistance of the cushion; and that represented by F B, which is the only one that can remain, would carry the ball towards E."

"That would be so if both the ball and cushion were quite devoid of elasticity, but in so far as these bodies are elastic no motion will be lost. Here is a sketch in which I have represented the impact of a ball on the cushion when the direction of the motion is perpendicular to the cushion (Fig. 52): E represents the ball, and C D the cushion, at the first instant of contact. The motion of the ball continues after this in the

same direction, but with a rapidly decreasing velocity, for by its progress the shape of the cushion at E is changed into that shown at F, and the ball itself tends to assume the flattened shape represented by the ellipse at F. These changes of form are resisted by both materials with an energy increasing with the amount of deformation, and this resistance destroys the motion of the ball, which is for an instant stationary in the position represented at F, all the force due to its motion having been expended in bringing about the alteration in the forms of the materials there shown. Had these materials no elasticity whatever, they would simply retain their new form, and no further motion would ensue. But all substances, though in very different degrees, tend to recover their forms when thus altered, and this property is termed elasticity. If on the withdrawal of the deforming pressure, the recovery of the original form is immediate and complete, the elasticity is said to be perfect, and if there were absolutely no tendency to recover the shape *elasticity* would be wanting altogether. As a matter of fact, neither of these extreme conditions is realized by any substances with which we are acquainted. Supposing for the moment that the materials we are dealing with possess perfect elasticity, they would recover their forms by passing in inverse order through the same phases of alteration as in the first stage of the impact, and this recovery would necessarily give the ball a precisely equal impulse in the opposite direction, so that it would rebound from the cushion with exactly the same velocity as before impact. This is again an instance of the equality of action and reaction. So that, admitting, as for the present we may, that the elasticity is perfect, the force along D B (Fig. 51), will be exchanged for one in an opposite direction, B D."

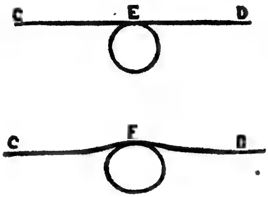


Fig. 52.

"I had entirely overlooked the elasticity," said Tom. "I now see my way clearly; for, in that case, there must be two forces acting in the directions B D, B E, which will, of course, drive the ball along the diagonal B C."

"Your demonstration is perfectly correct, my boy; and I think you will now admit that I could not have adduced a more

beautiful instance of the composition and resolution of forces; for, in the first place, you resolve the diagonal force A B into two others, and then, by aid of the laws of action and reaction, you recompound again, so producing another diagonal force B C equal to A B."

"But I think you told us that the angles of incidence and reflection were only equal when the rebounding body was perfectly elastic."

"Clearly so: the force D B must be exchanged for an equal one, B D, or else the angle A B D cannot be equal to the angle D B C; but I will render this fact still further intelligible by another diagram. Let B, as in the former case, represent the cushion upon which the imperfectly elastic body impinges in the direction A B. The force may, of course, be resolved into two others, viz., into D B and F B; the force D B, however, instead of being replaced by the opposite one B D, will now be represented by the shorter line B G; or by B H or B I, according to the degree of elasticity. If we, therefore, complete the parallelograms, B C′, B K, or B M will be the diagonal path of the body —making, as you perceive, the *angle of reflection*, D B C′, greater than that of *incidence*, A B D; and, were the body perfectly inelastic, the force D B would be wholly destroyed, and, the force B E alone surviving, the body would be carried along the line B E. I have now," continued Mr. Seymour, "explained to you the principal laws which govern those forces by which your ball or marbles are actuated. It is true that in practice you cannot expect that the results should accurately coincide with the theory, because, in the first place, you cannot obtain marbles that are of equal density and elasticity and of true figure; and, in the next, there will be obstacles against which it is impossible to guard. The spinning of the marble will also have a material influence on its motion, as we have already discovered. In the game of billiards, where every obstacle is removed, as far as art can assist, the theory and practice are often strangely discordant."

Tom here said that he should like to know whether not only the directions but also the velocities of two billiard-balls, after collision, could be calculated.

Mr. Seymour replied that there were several propositions connected with this subject explained in elementary treatises on mechanics. By these the velocities of two bodies, after collision,

could be calculated, when the masses, velocities, and elasticity of the bodies were given.

"Could, then, the exact path and velocity of a billiard-ball be calculated from these data?" asked Tom.

"There are other circumstances which would require to be taken into consideration," replied Mr. Seymour. "Thus, the rolling of the ball along the table is an element of great importance, for a skilful player can, according to the place on which he hits the ball with the cue, make it follow the ball struck, or rebound from it, or remain stationary after imparting its momentum to the object ball. If the rotatory motion of the balls be left out of account, the investigation of the velocities is quite easy."

Mr. Seymour then showed an experiment with the balls on the billiard-table, which puzzled Tom completely until he had a hint of its explanation. The experiment was performed by placing three balls in a row and in close contact. The centre ball was then carefully removed without disturbing the others, so that the space between these was, of course, exactly the diameter of the ball withdrawn. The latter was placed at the distance of a foot or two, and in a line with the opening; and when Mr. Seymour took a cue and propelled this ball so that it passed between the other two, and did not in the least move them, Tom was quite amazed, and asked his father to repeat the stroke, which he did several times, and always with the same result. Tom himself then tried a dozen times, but on each occasion he did not fail to make all the balls roll about the table. Mr. Seymour then explained that the trick depended upon a reaction; and showed that in striking the ball, he gave a blow in a somewhat downward direction, so that the ball not only went forwards, but actually rose a little from the table, and thus made a leap over the space between the two stationary balls, although a spectator would suppose it had simply rolled along.

CHAPTER XIV.

Knowledge gained betimes, and which appears,
Though solid, not too weighty for his years,
Sweet in itself, and not forbidding sport.

WHEN the children had reassembled, according to their father's appointment, he informed them that the subject of their present conversation should be the *Centre of Gravity of Bodies*, for the illustration of which he had several interesting toys in readiness.

"Can you tell me, Tom," said he, "what is meant by the centre of gravity of a body?"

"Its central point," answered the boy.

"Certainly not: the central point is its centre of figure, not of gravity; and it is only when a body is of uniform density, and of regular figure, that these centres of figure and of gravity coincide, or fall in the same spot."

"I now remember," cried Tom, "that the centre of gravity

is that point about which all the parts of a body exactly balance each other."

"Now you are right: it is, in other words, that point in which the whole weight of a body appears, as it were, condensed, or upon which the whole gravitating influence seems concentrated. Consequently, so long as the centre of gravity is supported, the body can never fall; while, in every other position, this point will endeavour to descend to the lowest place at which it can arrive."

"Have all bodies, whatever may be their shape, a centre of gravity?" asked Louisa.

"Undoubtedly."

"And you say," continued Louisa, "that every body will fall, if this point is not supported?"

"Infallibly. And now, Tom," said Mr. Seymour, "can you tell me what is meant by the *line of direction?*"

The young philosopher was unable to answer this question, and

Fig. 53.

Fig. 54.

his father, therefore, informed him that if a line were drawn from the centre of gravity of a body to the centre of the earth, such a line would be termed the *line of direction;* and he was also informed that if this line fell within the base of a body, such a body was sure to stand—but never otherwise.

Louisa observed that she was not quite sure she understood her papa's meaning, and therefore begged for further explanation.

"I will exemplify it," replied Mr. Seymour, "by a drawing. Fig. 53 represents a load of stones in a cart moving upon a sloping road; this load being low down in the cart, the centre of gravity will also be low, and the line of direction will fall much within the wheels; there cannot, therefore, be any danger of such a cart being overturned. But in Fig. 54 the centre of gravity is raised much higher, and the line of direction falling without the wheels, the load will not be supported, and must consequently fall. These figures," added Mr. Seymour, "will also explain a fact which you must have frequently observed, that a body is stable or firm in proportion to the breadth of its base; hence the difficulty of sustaining a tall body, like a walking-stick, upon its narrow base, or that of balancing a hoop upon its edge, or a top upon its point; while, on the contrary, it is almost impossible to upset the cone or the pyramid, since, in the latter cases, the *line of direction* falls within the middle of the base, the centre of gravity of the body being necessarily low.

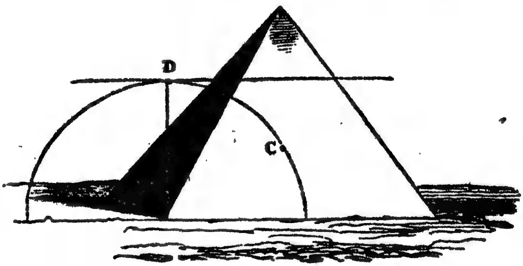


Fig. 55.

Thus the pyramid I here show you a drawing of (Fig. 55) cannot be upset until C, its centre of gravity, has been raised up to D, beyond which position the line of direction would fall outside of the base."

"I suppose," observed Louisa, "that this is the reason why carriages, when too much loaded, are so apt to upset."

"Say when too much loaded on their *tops*, and you will be right. As you now, I trust, understand this part of the subject,

let us proceed a step further. If you take any body, with a view to suspend it, is it not evident, that if it be suspended by that point in which the centre of gravity is situated, it must remain at rest in *any* position indifferently?"

"I thought," said Tom, "we had already settled that question."

"True, my dear boy; but there is another question of great importance arising out of it, and which you have not yet considered. Tell me, should the body be suspended on any other point, in what position it can rest?"

"I do not exactly understand the question."

"There are," replied his father, "only two positions in which it could rest, either where the centre of gravity is exactly *above*, or exactly *below*, the point of suspension; so that, in short, this point shall be in the *line of direction*. Where the point of suspension is *below* the centre of gravity, it is extremely difficult to balance or support a tall body by such a method, because the centre of gravity is always endeavouring to get under the point of support. Look at this diagram (Fig. 56), and you will readily comprehend my meaning. K is the centre of gravity of the diamond-shaped figure, which may be supported, or balanced, on a pin passing through it at M, as long as the centre of gravity K is immediately over the point of suspension M; but if that centre is removed in the slightest degree, either to the right or left of its place K, the body will no longer retain its erect position I K L, but it will revolve upon M, and place itself in the situation indicated by the dotted lines beneath the point M; and its centre of gravity will now be removed to N, directly *under* M, and in the line K L, which, as you well know, is the line of direction. Have I rendered myself intelligible?"

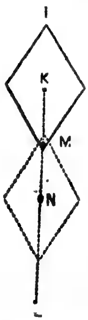


Fig. 56.

"I understand it perfectly," answered Tom.

"And do you also, my dear Louisa?"

Louisa's answer was equally satisfactory, and Mr. Seymour went on to state that the information they had now acquired would enable them to ascertain the situation of the centre of gravity of any plane surface which was portable, notwithstanding it might possess the utmost irregularity of shape.

Mr. Seymour now gave Tom an ordinary school slate, and asked him to find its centre of gravity. The boy proceeded to

do this in the manner which is indicated in the annexed cuts, Figs. 57 and 58. He first suspended the slate by means of a piece of string from the angle A, from which point a plumb-line

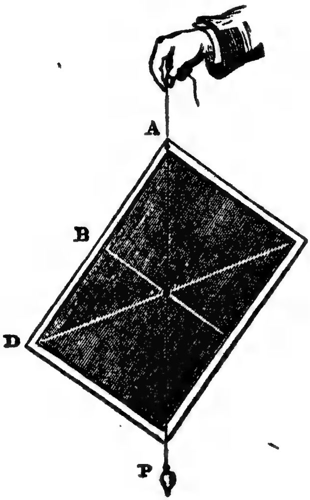


Fig. 57.

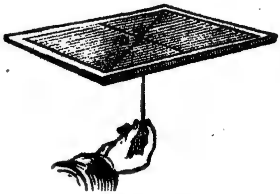


Fig. 58.

A P depended. The *line of direction* given by this was marked on the slate, and proved to be the diagonal joining the opposite corners of the slate. On repeating the operation, using the points B and D successively as points of suspension, Tom found that the three lines intersected each other at C, which he declared to be the centre of gravity, and verified his result by balancing the slate on the tip of a pencil, as shown in Fig. 58.

"It is really," observed Louisa, "a very simple method of finding the centre of gravity."

"It is," said Mr. Seymour; "but you must remember that it will only apply to a certain description of bodies. When they are not portable, and will not admit of this kind of examination, their centres of gravity can only be ascertained by experiment or by calculations, in which the weight, density, and situation of the respective portions must be taken into the account. Having proceeded thus far, you have next to learn that the centre of gravity is sometimes so situated as not to be *within* the body, but actually at some distance from it."

"Why, papa!" exclaimed Tom, "how can that possibly happen?"

"You shall hear. The centre of gravity, as you have just said, is that point about which all the parts of a body balance each other; but it may so happen that there is a vacant space at this point. Where, for example, is the centre of gravity of this ring? Must it not be in the space which the ring encircles?"

"I think it must," said Tom; "and yet, how can it be ever supported without touching the ring?"

"That point cannot be supported," answered his father, "unless the ring be so held that the line of direction shall fall within the base of the support, which will be the case when you poise the ring on the tip of your finger; or you may suspend it by a string, in which case it will be more stably supported than in the former position, because the centre of gravity will then place itself below the point of suspension; whereas, in the former case, the base is extremely narrow, and it will, consequently, require all the address of the balancer to prevent the centre of gravity from falling beyond it. When a body is in such a position that, on its position being slightly altered, gravity still tends to bring it back to its former position again, that position is said to be one of *stable equilibrium;* but when the body is so situated that when slightly displaced gravity tends to draw it still more from its position, that position is called one of *unstable equilibrium.*"

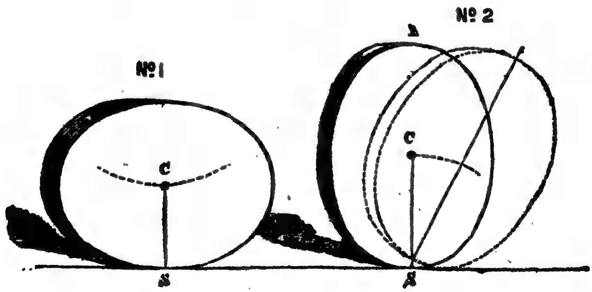


Fig. 59.

As neither Tom or Louisa professed to understand these last conditions, their father made the sketch of which a copy is annexed in Fig. 59, where a piece of board cut out into an oval

form is represented as balanced on its edge in two different positions. In No. 1 it is in a position of stable equilibrium, for if it be moved a little to either side the centre of gravity is raised, and therefore gravity pulls it back in the former position, in which the centre of gravity is at the lowest possible point; and only in this position, Mr. Seymour explained, would a body rest so long as it was free to move. No. 2, on the other hand, represents the same oval block, balanced indeed on the end of its longer axis; but the least displacement would cause the centre of gravity to descend, and therefore the oval would roll over. This, therefore, is a position of unstable equilibrium.

Tom said he remembered some story about Columbus balancing an egg on one end, and he wished to know how it was done.

"The method in which that great discoverer," replied Mr. Seymour, "solved the problem was, it is usually stated, that of slightly breaking a little of the shell, so as to flatten the end; but I believe an egg may without much difficulty be poised on the broader end without disturbing the shell. The mode of doing this is to shake the egg violently so as to break the yolk, which, having a greater specific gravity than the white, sinks to the bottom, and by bringing a greater proportion of the weight

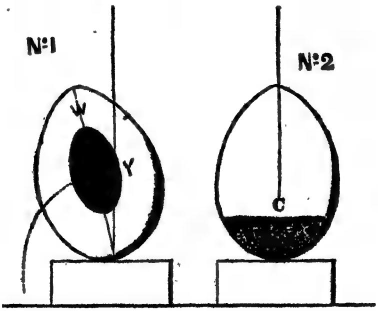


Fig. 60.

to the base, lowers the centre of gravity, and thus renders it possible to poise the egg on a surface where the feat would be impossible with the yolk occupying its usual central position."

Mr. Seymour again illustrated his statements by a sketch,

which we also present to our readers in Fig. 60 in order that they may have the same opportunity of understanding the matter as had Tom and Louisa. In this figure, No. 1 represents the egg in its natural condition. Here the yolk (Y) is in its ordinary position—in the middle of the egg, and the centre of gravity of the whole is also near the middle. In No. 2, which represents the egg with the yolk settled at the bottom, the centre of gravity is much lower. Mr. Seymour took occasion to remark that positions of unstable equilibrium could, in practice, never be maintained, as the smallest imaginable disturbance, such as the movement of the air, or any tremor accidentally communicated to the bodies, would immediately cause a descent of the centre of gravity. The cases in which unstable equilibrium appears to exist will always be found, on examination, to depend upon some degree of friction, or some yielding of the materials. The egg may be balanced on its end in the manner just explained, provided the trial is made on a tablecloth, which, by its yielding, will provide some small amount of support; but the experiment will be found impracticable when attempted on a surface of polished marble.

"As you are now," Mr. Seymour proceeded, "in possession of all the leading principles upon which the centre of gravity depends, I shall put a few practical questions to you, in order that I may be satisfied you understand them. Tell me, therefore, why a person who is fearful of falling, as, for instance, when he leans forward, should invariably put forward one of his feet, as you did the other day, when you looked into Overton well?"

"To increase his base," answered Tom: "whenever I lean greatly forward, I should throw the line of direction beyond it, did I not at the same instant put out one of my feet, so as to extend my base, and thus to cause the line to continue within it."

"Rightly answered; and, for the same reason, a porter with a load on his back leans forward, to prevent his burden from throwing the line of direction out of the base behind. Did you ever observe the manner in which a woman carries a pail of water?"

"To be sure," said Tom; "she always stretches out one of her arms."

"The weight of the pail," continued Mr. Seymour, "throws the centre of gravity on one side, and the woman, therefore,

stretches out the opposite arm, in order to bring it back again into its original situation; but a pail hanging on each arm is carried without difficulty, because they balance each other, and the centre of gravity remains supported by the feet."

"I see," said Louisa, "that all you have said about the woman and her pail must be true; but how could she have learned the principle which thus enabled her to keep the centre of gravity in its proper place?"

"By experience. It is very unlikely that she should ever have heard of such a principle, any more than those people who pack carts and waggons, and yet make up their loads with such accuracy as always to keep the line of direction in, or near, the middle of the base. But, to proceed to another example: have I not frequently cautioned you against jumping up suddenly in a boat? Can you tell me upon what principle such an operation must be attended with danger?"

"I suppose," said Tom, "for the very same reason that a waggon is more likely to be overturned when its top is too heavily laden: it would elevate the centre of gravity, and thereby render the boat more liable to be upset."

Mr. Seymour observed that after this lesson he thought the balancing which Tom and Louisa had witnessed at the circus, and the feats of Blondin which they had seen last year, would cease to appear so miraculous. Louisa declared that she had now discovered the whole mystery.

"You have doubtless perceived," said her father, "that the art entirely consists in dexterously altering the centre of gravity upon every new position of the body, so as constantly to preserve the line of direction within the base. The rope-dancers effect this by means of a long pole, the ends of which are loaded by weights, which they hold across the rope. If you had paid sufficient attention to their movements, you must have perceived how steadily they fix their eyes on some object near the rope, so as to discover the slightest deviation of their centre of gravity to one or the other of its sides, which they no sooner detect, than they instantly rectify it by a countervailing motion of their pole, and are thus enabled to preserve the line of direction within the narrow base. This very same expedient is frequently practised by ourselves: if we slip or stumble with one foot, we naturally extend the opposite arm, making the same use of it as the rope-dancer does of his pole."

"What an interesting subject this is," cried Louisa, "and how many curious things it is capable of explaining!"

"Indeed it is; and I shall take an opportunity of pointing out several specimens of art which are indebted for their stability to the scientific application of the principle we have been considering. But I have now a paradox for you, Tom."

"Let us hear it, papa."

"How comes it that a stick, loaded with a weight at the upper extremity, can be kept in equilibrio on the point of the finger with much greater ease than when the weight is near the lower extremity; or, for instance, that a sword can be balanced on the finger much better when the hilt is uppermost?"

"That is, indeed, strange. I should have thought," replied Louisa, "that the higher the weight was placed above the point of support, the more readily would the line of direction have been thrown beyond the base."

"In that respect you are perfectly right; but the balancer will be able to restore it more easily in one case than in the other; since, for reasons which you will presently discover, the greater the circle which a body describes in falling, the less will

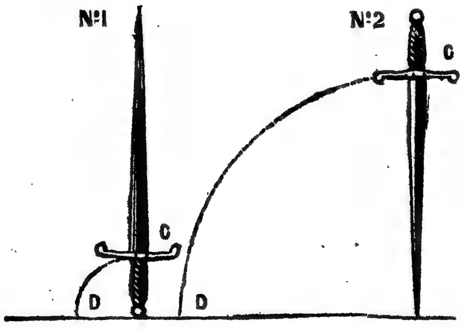


Fig. 61.

be its tendency to fall. Look at the sketch (Fig. 61) which I have prepared for the explanation of this fact, and I think you will readily comprehend the reason of it.

"When the weight is at a considerable distance from the point of support, its centre of gravity, in deviating either on one

side or the other from a vertical direction, describes a larger circle, as No. 2, than when the weight is very near to the centre of rotation or the point of support, as in No. 1. But in a large circle, an arc of any determinate length, such as an inch, for example, gives an angle which deviates much less from the vertical than if the circle were less—as may be seen by setting off equal lengths on the curves in No. 1 and No. 2; and the sword at No. 2 will not have so great a tendency to deviate farther from the vertical as that at No. 1. You see, then, that it is less difficult to balance a tall than a shorter pole; and it is for the same reason that a person can walk with greater security on high than on low stilts."

"That is very clear," said Louisa, "although, before your explanation, I always associated the idea of difficulty with their height."

"I suppose," added Tom, "that the whole art of walking on stilts may be explained by the principles you have taught us."

"Undoubtedly it may; for the equilibrium is preserved by varying the position of the body, and thus keeping the centre of gravity within the base."

"It must be a great exertion," observed Louisa.

"Before custom has rendered it familiar; after which, there is no more fatigue in walking on stilts than in walking on our feet. There is a district in the south of France called the Desert of Landes, which runs along the sea-coast between the mouths of the Adour and Gironde, where all the shepherds are mounted on stilts, on which they move with perfect freedom and astonishing rapidity; and so easily does habit enable them to preserve their balance, that they run, jump, stoop, and even dance, with ease and security."

"How very odd!" said Tom; "what can be their motive for such a strange habit?"

"Its objects," replied his father, "are important: to keep the feet out of the water, which, during the winter, is deep on the sands; and to defend them from the heated sand during the summer; in addition to which the sphere of vision over so perfect a flat is materially increased by the elevation, and the shepherds are thus enabled to see their flocks at a much greater distance. They cannot, however, stand perfectly still upon their stilts without the aid of a long staff, which they always carry in their hands: this guards them against any accidental

trip, and, when they wish to be at rest, forms a third leg that keeps them steady."

"I suppose," said Louisa, "that the habit of using these stilts is acquired while they are very young?"

"It is, my dear; and it appears that the smaller the boy is, the higher are his stilts—a fact which affords a practical proof of the truth of what I have just stated."

"The stork is said, in my work on 'Natural History,' to be always walking on stilts," said Louisa; "and yet it does not appear to fatigue him."

"That is very true," replied the father; "but you must remember that nature has furnished the bird with a provision, by which the legs are kept extended without any exertion of the muscles, in the manner of certain springs—a structure which enables it to pass whole days and nights on one foot without the slightest fatigue."

"But, papa," said Tom, "I have yet some more questions to ask you on the subject of balancing. I am not at all satisfied about many of the tricks that we saw last year; indeed, I cannot believe that many of those astonishing feats will admit of explanation from the rules you have just given us."

"I very well know to what you allude," replied Mr. Seymour. "Many singular deceptions are certainly practised by removing the centre of gravity from its natural into an artificial situation, or by disguising its place; thus, a cylinder placed upon an inclined surface may be made to run *up* instead of *down* hill. I can even appear to balance a pailful of water on the slender stem of a tobacco-pipe simply placed on the table and projecting over its edge, without it being in any way fastened."

"Oh! do, papa, show us that," cried Tom and Louisa together.

A tobacco-pipe not being at hand, Mr. Seymour performed the experiment in the manner indicated in Fig. 62, stating that he used the stick D C instead of the pipe, which he would have placed in a similar position with the bowl at E, against which the stick G E would abut; but he obtained the like hold for G E by making at E a notch in the stick D C. The children were not a little surprised to see the pail apparently supported by a stick merely laid on the table, and seemingly ready to tilt up on the slightest touch; and their astonishment was not diminished when Mr. Seymour filled the pail, still in the position represented

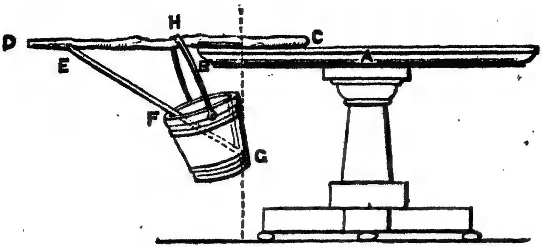


Fig. 62.

in the cut, with water. A modification of the experiment, in which a 56 lb. weight took the place of the pail, was afterwards shown to them, and the arrangement for this purpose will become obvious to our readers by an inspection of the annexed cut, Fig. 63.

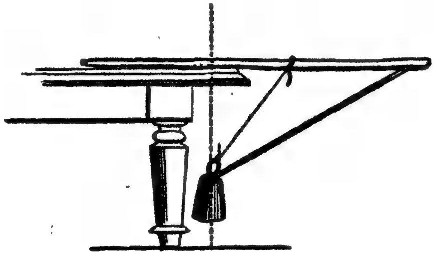


Fig. 63.

"I shall be better able," said Mr. Seymour, "to explain the nature of these deceptions by toys, in which the same principle is made use of, and which will probably prove not less instructive to us than they will be amusing as playthings for John. But before showing you the toys, I will exhibit by means of this billiard-ball and these two cues the curious experiment of making the ball appear to run up an incline."

Mr. Seymour laid the two cues flat upon the table in a nearly parallel position, and placing the ball between them at the small ends (as at C, Fig. 64), the ball rolled towards the thick ends of the cues. This somewhat puzzled Tom at first, but he was easily made to understand that the rise of the ball was apparent

Fig. 64.

only, and that in reality its centre of gravity was descending all the time. And our readers can have no difficulty in seeing how this happened if Fig. 65 be examined. A shows the cues looked

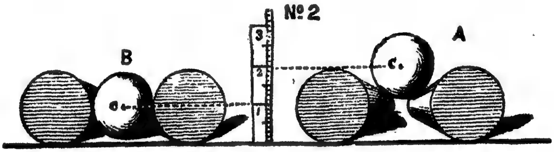


Fig. 65.

at end-ways, and the ball at the commencement of its journey, when its centre of gravity, C, is just two inches above the table, while B shows the ball at the end of its course, during which C has descended to one inch above the table. To make the

Fig. 66.

matter, if need be, still clearer, we give in Fig. 66 a side view of the cues and the ball in the two extreme positions.

"I have here," said Mr. Seymour, as he opened a large wooden box, "a collection of figures, which will always raise themselves upright, and preserve the erect position, or regain it whenever it may have been disturbed."

He then arranged these figures in battalion on the table, and striking them flat by drawing a rod over them, they immediately started up again as soon as it was removed.

"The figures," said Mr. Seymour, "are made of the pith of the elder-tree, which is extremely light, and is affixed to the

half of a leaden bullet; on account, therefore, of the disproportion between the weight of the figure and that of its base, we may exclude the consideration of the former, and confine our attention to the latter. The centre of gravity of the hemispherical base is, of course, in its axis, and therefore tends to approach the horizontal plane as much as possible; and this can never be accomplished until the axis becomes perpendicular to the horizon. Whenever the curved surface is in any other position, the centre of gravity is not in the lowest place to which it can descend."

Mr. Seymour also produced a pair of the figures called

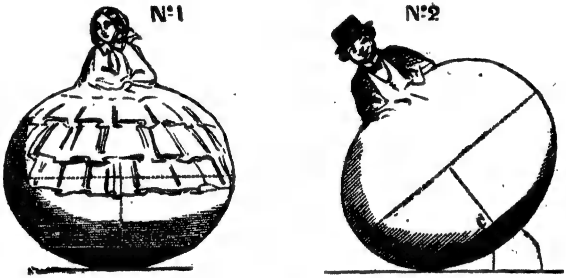


Fig. 67.

tumblers (Fig. 67, No. 1 and No. 2). He said that in these toys likewise the centre of gravity was brought as low as possible by loading with lead; and he explained, in a manner which we need not repeat in detail, that the figures could not be displaced from the upright position into which they settle without their centres of gravity being thereby raised.

"I understand it perfectly," said Tom. "When the axis is vertical, the centre of gravity will be in its lowest point, or as near the earth as it can place itself; when, therefore, the figure is pressed down, the centre of gravity is raised, and consequently, on the removal of that pressure, it will descend to its original position, and thus raise the figure."

"I see you understand it. Here, then," continued Mr. Seymour, "is another toy in further illustration of our subject. It consists of a small figure supported on a stand by a ball, which

is quite loose; and yet it is made to turn and balance itself in all directions, always recovering its erect position when the force applied to it is removed. The two weights, in this case, bring the centre of gravity considerably *below* the point of suspension or support, and therefore maintain the figure upright, and make it resume its perpendicular position after it has been inclined to either side; for the centre of gravity cannot place itself as low as possible without making the figure stand erect."

"That is very evident," cried Louisa.

The figure which thus balances itself, and turns round on one foot, is doubtless familiar to most of our readers; but an ingenious, because ready and simple, arrangement to illustrate the effect of lowering the centre of gravity, so as to bring it beneath the point of support, was devised by Tom himself. He simply stuck the blades of two pocket-knives into a cedar pencil, in the manner shown in Fig. 68, and thus made the pencil stand upright upon the tip of his finger.


Fig. 68.

"I shall next exhibit to you," continued Mr. Seymour, "a toy that furnishes a very good solution of a popular paradox in mechanics; viz., *A body having a tendency to fall by its own weight, how to prevent it from falling by adding to it a weight on the same side on which it tends to fall.*"

"That is indeed a paradox!" exclaimed Louisa. "The next time I see the gardener sinking under the load of a heavy sack, I shall desire him to lighten his burden by doubling its weight."

"Will you, indeed, Miss Pert? I do not think so, after you have seen the operation of the toy I am now about to exhibit (Fig. 69). Here, you perceive, is a horse, the centre of gravity of which would be somewhere about the middle of its body; it is, therefore, very evident, that if I were to place its hinder legs on the edge of the table, the *line of direction* would fall considerably beyond the base, and the horse must be precipitated to the ground. You will, however, perceive that there is a stiff wire attached to a weight which is connected with the body of the horse, and by means of such an addition, the horse prances with perfect security at the edge of the precipice; so that the figure which was incapable of supporting itself is actually prevented from falling by adding a weight to its unsupported end!"

The children admitted the truth of this statement, but were not immediately prepared to explain it.

"The weight, indeed, appears to be added on that side; but, in reality, it is on the opposite side," said the vicar.

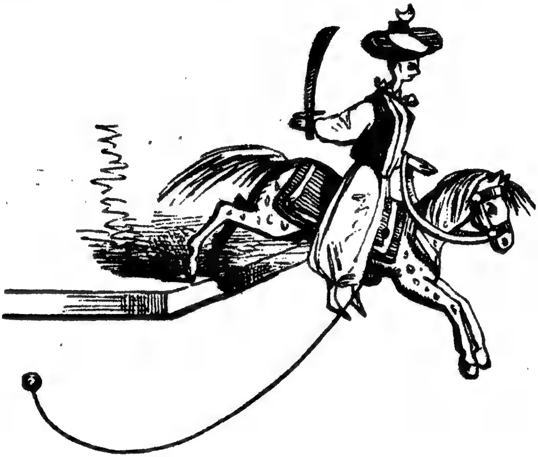


Fig. 69.

"In order to produce the desired effect," observed Mr. Seymour, "the wire must be bent, so as to throw the weight far back under the table; by which contrivance, since the centre of gravity of the whole compound figure is thrown into the leaden weight, the hind legs of the horse thus become the point of suspension, on which the ball may be made to vibrate with perfect security."

"Now I understand it," cried Tom: "instead of the weight supporting the horse, the horse supports the weight."

"Exactly so. You perceive, therefore, from these few examples, that the balancer, by availing himself of such deceptions, and combining with them a considerable degree of manual dexterity, may perform feats which, at first sight, will appear in direct opposition to the laws of gravity. There is also another expedient of which the balancer avails himself, to increase the wonder of his performances, and that is the influence of rotatory

motion, which, you have already seen, may be made to counteract the force of gravity."

"I remember that the most surprising of all the tricks I witnessed was one in which a sword was suspended on a key, which turned round on the end of a tobacco-pipe; on the top of the sword a pewter plate was, at the same time, made to revolve with great velocity."

"I well remember the trick to which you allude. The rotatory motion prevented the sword from falling, just, as you will hereafter find, the spinning of the top will preserve it in an erect position. There is also another effect produced by rotatory motion, with which it is essential that you should become acquainted. You no doubt remember that the velocity of a body will compensate for its want of mass. A number of bodies, therefore, although incapable of balancing each other when in a state of rest, may be made to do so by imparting to them different degrees of motion. I believe that you are now acquainted with all the principles upon which the art of balancing depends; and I have little doubt, should we again witness a performance of this kind, that you will be able to explain the tricks which formerly appeared to you so miraculous."

CHAPTER XV.

> **I loved the brimming wave that swam**
> **Through quiet meadows round the mill,**
> **The sleepy pool above the dam,**
> **The pool beneath it never still.**

ONE of Tom's favourite amusements was the construction of little models of water-wheels, which, to the great delight of his brother and sisters, he used to set in motion under some tiny cascade formed by the stream that traversed the grounds. And it is not difficult to account for the boy's mechanical turn having taken this direction; for the little stream, after sparkling down the rocky dell, and then meandering for a mile or more amid pleasant meadows, joined a small river; and on the latter, at a short distance below the confluence, was situated an old-fashioned picturesque mill with a large water-wheel. The mill was built in a prettily wooded valley, and a walk to it by the path which followed the stream was a frequent ramble of the Seymours. It was, then, quite natural that Tom should try to

fashion for himself imitations of the water-wheel, the action of which he had always watched with lively interest. Often on bright summer days had Tom reclined on the grass, or stood on the narrow foot-bridge, viewing the majestic revolutions of the great black wheel, as its dripping boards glittered and flashed in the sunlight. Often had he contemplated the perfect reflections of the trees in the calm reservoir above the mill, and watched the water rolling over the sluice in a clear and transparent mass, to break and tumble into the buckets of the wheel, which it quitted as a rivulet of snow-white foam, hurrying along the channel beneath to rejoin its parent stream. Often had he listened to the strange but soothing commixture of sounds which was made up of the murmur of the water falling over the weir, of the ceaseless splash of the wheel, and of the subdued hum from the machinery within the mill. Sometimes he thought how strange it was that the water which flowed down their own little stream at Overton should thus help to grind the farmer's corn; and he pondered over the means by which this was accomplished, until he understood the use of every wheel; but still it seemed wonderful that some pieces of wood, iron, and stone, properly shaped and constructed, were able to make the water do work for men by turning their corn into flour.

But on revisiting the mill for the first time since his return home, Tom discovered a change in the scene, which, in his eyes, imparted to it additional interest. He found a party of workmen were engaged in constructing a bridge for carts and carriages across the river in the immediate vicinity of the mill. Vehicular communication between the opposite banks of the river had hitherto been carried on by a circuitous route, which the new structure was designed to avoid. Tom now saw the work almost at its commencement, and he viewed with much curiosity the cranes, tools, and other machines which were employed. His attention was especially attracted by a pile-driving engine, in the action of which he did not fail to recognize some of those laws of falling bodies upon which Mr. Seymour had been descanting. Tom was, however, desirous that his papa should visit the spot and explain some points which had not yet been discussed; and Mr. Seymour at once assented, observing that their philosophical studies could not be pursued in any better way than by viewing the actual applications of science to the useful arts. It was accordingly arranged that the whole party should accompany

Mr. Seymour the next afternoon to see the operations of the bridge-builders. As this visit led to much instructive conversation in reference to the subjects on which our young friends were now desirous to obtain more information, we venture to request the reader's company on this occasion, on the presumption that he also may be animated by the like desire.

The first object which arrested the attention when the party reached the spot, was the machine with which the men were driving into the ground, at the river's bank, large pieces of timber called "piles." This was done by allowing a block of iron to descend by the force of gravity upon the head of the pile, the ponderous lump of metal being guided in its ascent and descent by two upright pieces of timber, between which it moved in grooves. The block of iron, or *ram*, as the workmen called it, was raised by means of a rope, which passed over a pulley at the top of the timber framing. One end of this rope was attached to the ram, and the other end was connected with a number of smaller ropes, each of which being pulled by a man, the ram was drawn to the top of the machine, and at a certain signal all the men let go their hold at the same time, and the weight then descended with a heavy thud upon the head of the pile.

Tom inquired if the force of the blow struck by the ram was not due to its *momentum*.

Mr. Seymour asked Tom if he remembered the meaning they had before given to the word "momentum."

"It is," replied Tom, "the product of the *mass* of a moving body into its *velocity*."

"That is quite correct; and I believe I pointed out that it is convenient to have a name for this product—as, for instance, in expressing the law of action and reaction, we said that any force acting between two bodies free to move, always produces equal *momenta* in opposite directions. In all such cases the notion of *momentum* is very suitable; but in the present instance it is quite inapplicable."

"Yet, I am sure," said Tom, "that Mrs. Marcet defines *momentum* as the force or power with which a body in motion strikes against another body, so as to set the latter in motion."

"But observe that the case contemplated in that definition is not at all the one that we have before us; for the definition supposes, and ought, indeed, to have expressed, that the second body is free to move. When a billiard-ball in motion strikes

one at rest, the effect of the blow may be measured by the *momentum* imparted to the second ball. The case is one of action and reaction; and in like manner, if the pile were perfectly free to move, we might consider the case simply as one in which *momenta* are concerned. But as the pile-engine is used not for the purpose of imparting velocity to the pile, but for overcoming the resistance which the soil offers to its insertion, it is plain that the efficiency of the engine must be measured by the degree in which it accomplishes this. Now, we may assume that the resistance offered by the ground to the descent of that pile the workmen are now driving in does not vary—at least, for the next few strokes. Now, tell me whether you think that the 'force of the blow,' as you phrase it, would not simply mean the extent to which the pile is forced into the ground?"

"Certainly," replied Tom, "if one blow of the ram caused it to penetrate the ground one inch deeper, and another blow made it descend two inches, I should say that the second blow had twice the force of the former."

"Very well, then, I must tell you that the *momentum* of the ram is *not* the measure of the 'force of the blow,' in that sense. But it will now be necessary for me to make you acquainted with a notion upon which is based all the exact science of our day. You see clearly that the pile-driving engine is used for the purpose of moving something against a resistance. You will, in fact, find that the action of every machine and every tool requires the moving of something against a resistance; and it is the same with all operations which are called 'work.' The bricklayer who carries a hod of mortar up a ladder moves it against the resistance of gravity; the joiner who smooths a board moves his plane only by overcoming the resistance offered by the cohesion of the parts of the wood. As you, no doubt, at once perçeive, the bricklayer who would carry up two hods of mortar instead of one, or who would carry one up a height of twenty feet instead of ten, would do just twice as much work."

"It is quite clear that he would," answered Tom.

"Now, state in general terms in what you would find the measure of such a labourer's work."

"I should take the number of hods, and the height they were carried, together."

"That is, you would estimate the work by the weight and the height jointly; or, in other words, you would take the product

of the resistance, in pounds say, into the distance, in feet for example, through which it is overcome, as the measure of the work performed."

"That clearly would give us," replied Tom, "a just measure of the man's work."

"Now, I want you to extend this same idea of *work* to all cases of motion against resistance. In the first place, observe that all manner of resistances can be represented by weights. For example, the resistance which the cohesion of the wood offers to your plane is equivalent to the resistance which gravity offers to your lifting vertically some certain weight."

Tom and Louisa both declared that they quite understood this. But Mr. Seymour told them, that although they doubtless quite saw that the work performed in raising a weight, or planing a board, was expressible as the product of the resistance into the distance the weight was raised, or the plane was moved, they must not suppose that they were properly acquainted with the idea he was trying to impart to them until they had themselves recognized its application in a great number of different cases.

"But," he continued, "if you will, for the present, bear in mind what *work* is, in the scientific sense—that it is always measured by the amount of the resistance, multiplied into the distance through which the motion takes place against the resistance—I can enunciate an important principle, a very important principle, which as universally applies to mechanical actions as the law of gravitation does to matter. This principle will solve our questions as to the action of the pile-driving engine, and of all other machines—levers, pulleys, wheels, and mechanical combinations of every kind. It is this: *no work whatever is done by any machine of itself; a machine can do only the amount of work which is done upon it.*"

"What!" cried Tom, "do not the pulley, and the wheel and axle, and the lever increase power, so that with their help men are able to do work which they could not possibly perform without?"

"I must ask you to keep to the strictly scientific sense of the word 'work,'" replied Mr. Seymour, "and to observe that there is a vagueness about the phrase 'increase of power' as you are now using it. I repeat—no lever, or pulley, or wheel, or any possible combination of these, can increase a man's power of doing *work*. But you will better understand my meaning by

an example. Look at the workman who is raising up the edge of that large block of stone by means of an iron lever or crow-bar, while the other places a wooden roller beneath it. Observe that in order to raise the stone only one or two inches, he has to press down the end of the lever through a distance of two or three feet. If we made the proper measurements, we should find that the pressure of the man's hand on the long arm of the lever, multiplied into the distance through which he moves it, is exactly equal to the weight of the stone on the short arm of the lever, multiplied into the distance through which it is raised."

"I see now," said Tom, "that the *work* done by the end of the lever under the stone must, in that case, be equal to that done by the man at the other end. Yet he could not have moved the stone at all without the lever."

"That is true; but observe that the lever is simply a device for changing the proportion of the two factors, resistance and distance, which make up the man's work, while their product remains the same; and we should find, by examining every one of the mechanical powers, that the same thing obtains. Now, let us apply this principle to the pile-driving engine. There, you see the heavy block of iron remaining on the top of the pile while the workmen are resting. Gravity is acting upon the ram; but in its present position, this is quite inoperative to urge the pile downwards. *Work* must be expended in raising the ram before any useful effects can be produced on the pile; and I need not tell you that the work so expended is measured by the weight of the ram multiplied into the vertical height it is raised; and you, perhaps, now understand that on descending, the *work* the ram will perform in driving down the pile must be exactly equal to that which is done by the men in raising it. But, come, let us put the matter into a numerical form. You see there are now six men pulling at ropes which raise the ram, and, assuming that each man pulls with the force of about 50 pounds, we may take the weight of the ram as 300 pounds. Now, supposing they draw it up 4 feet, can you tell me what amount of work they would do?"

"It would be four times 300," replied Tom, "or 1,260 pounds."

"No, do not say 1,200 *pounds*," observed Mr. Seymour, "for the 1,200 represents neither pounds nor feet, but *units of work*; yet, in order to express the denominations in which these units are calculated, it would not be improper to say 1,200 foot-pounds.

Well, by the fall of the ram from a height of 4 feet, let us suppose the pile is driven in to the extent of 1 inch, then I say that the resistance it experiences in entering the ground would be such that, multiplied by $\frac{1}{12}$—which is the value of an inch expressed in feet—it would amount to 1,200."

"That," said Tom, "would be just 14,400 pounds, I suppose."

"Certainly," replied Mr. Seymour; "and that is as much as to say that we should have to place a *weight* of nearly 7 tons upon the top of the pile in order to thrust it into the ground. But, now, if the ram be drawn to the height of 16 feet instead of 4, what would be the effect on the pile?"

"The work done in raising it would be four times greater, and therefore it would do four times as much work upon the pile—that is, it would drive it 4 inches into the ground."

"That is quite right," said Mr. Seymour; "and now calculate for me, with this paper and pencil, from what you know of the laws of falling bodies, the velocities which the ram would possess at the instant of striking the pile."

Tom remembering that a body which has fallen from rest has a velocity proportional to the time it has been falling, and at the rate of 32 feet for each second, calculated the times which a body occupies in falling 4 and 16 feet respectively; and, of course, found that these times were half a second and 1 second. Hence he affirmed that the ram falling 4 feet would strike with a velocity of 16 feet per second, and falling from a height of 16 feet, it would have acquired a speed of 32 feet per second.

"And therefore," observed Mr. Seymour, "the effect of doubling its velocity would be quadruple to its useful effect. And you would in like manner find that this useful effect, or power of doing work, would always be proportional to the *square of the velocity;* whereas the *momentum* is, as you know, proportional to the velocity simply. The power of doing work possessed by a moving body is often called *the energy due to motion*, and it is, remember, proportional to the *square of the velocity*. In fact, if you take the weight of any moving body in pounds, divide it by 32×2, and multiply the quotient by the square of the velocity expressed in feet and seconds, you will find the number of foot-pounds, or units of work, the body will do before it comes to rest."

Tom now desired to know whether the power of the water-wheel for doing work could be measured.

"But may not water and other bodies descend from a higher to a lower level without performing any work at all?" asked Tom. "For instance, if the mill were stopped, or if the wheel were altogether removed, the water would still descend as before when the sluice was opened, and yet no work would be done."

"Your remark is a very appropriate one, and it shows me that your mind is occupied with our subject," replied Mr. Seymour. "Let us suppose the wheel altogether removed, and the water to be flowing from the sluice as at present. Do you imagine there would then be any difference in the behaviour of the water on reaching the lower ground from that which it now exhibits?"

"Oh, certainly," cried Tom; "it would fall with a great dash and a roar, and perhaps would shake the ground, so that one might even feel this bridge trembling; there would be a great boiling and bubbling action below; some of the water would be dashed into spray; and the stones at the bottom would soon become worn."

"I declare," struck in Miss Villiers, "Tom is getting quite an adept at description. His account of what would happen if the water here splashed down unimpeded by a wheel, actually reminds me of a passage in this volume, which I was reading while you and Tom were talking to the workmen."

"I see," said Mr. Seymour, "you have brought a volume of your favourite poet with you. Well, will you read to us what the bard of 'The Seasons' says about a waterfall?"

Laura opened the book, and read with much taste and spirit the following lines:

"Smooth to the shelving brink a copious flood
Rolls fair and placid, where, collected all
In one impetuous torrent, down the steep
It thundering shoots, and shakes the country round.

At first, an azure sheet, it rushes broad;
Then whitening by degrees, as prone it falls,
And, from the loud-resounding rocks below
Dashed in a cloud of foam, it sends aloft
A hoary mist, and forms a ceaseless shower.
Nor can the tortured wave here find repose;
But, raging still amid the shaggy rocks,
Now flashes o'er the scattered fragments—now
Aslant the hollowed channel rapid darts;
And falling fast from gradual slope to slope,
With wild infracted course and lessened roar,
It gains a safer bed, and steals at last
Along the mazes of the quiet vale.'"

"All the actions," said Mr. Seymour, "which Tom mentioned, and all those which Thomson so finely describes as produced by a fall of water, involve movements against resistances, and therefore they represent *work*—I mean, of course, work in the scientific sense—not useful work. See how the buckets of the wheel seem to *carry* the water down, and deliver it to the channel at the bottom with comparative quietness. It is thus that the wheel draws away the energy of the waterfall to perform the work useful to man, instead of allowing that energy to expend itself in producing such actions as Tom and Thomson have described for us."

"I perceive now," said Tom, "that the wheel does not utilize the whole power of work of the fall, for there are still much splashing and other useless actions."

"There is always a great and unavoidable loss of energy in water-wheels, as well as in other prime movers. Thus it happens that even with a water-wheel of the very best construction, only about six-tenths of the total energy of the head of water can be rendered available for useful work."

"What becomes of the rest?" Tom asked.

"A part you have yourself already accounted for; another considerable part is spent against the friction, or resistance to motion, presented by the bearings of the wheel itself; and some of the energy of the fall, or head of water, is invariably spent in making the water warm. For I must tell you there is a wonderful connection between heat and work: the final result of work is often the production of heat; and heat, in its turn, can be made to do work, as in the notable example of the steam-engine."

"I see now," exclaimed Tom, "the meaning of a little experi-

"Certainly," replied his father; "the water-wheel, like the ram, can do only as much work as is done upon it; and that is done by the water in its descent from the higher to the lower level. And to measure the amount of work done upon the wheel in a minute, say, you have only to find the weight of the water which in that time passes from the sluice to the bottom of the wheel, and multiply by the height it has descended; for it is plain that this is the amount of work which would be expended in carrying the water up from the lower to the higher level, and it is also that which the water can perform in its descent."

"But may not water and other bodies descend from a higher to a lower level without performing any work at all?" asked Tom. "For instance, if the mill were stopped, or if the wheel were altogether removed, the water would still descend as before when the sluice was opened, and yet no work would be done."

"Your remark is a very appropriate one, and it shows me that your mind is occupied with our subject," replied Mr. Seymour. "Let us suppose the wheel altogether removed, and the water to be flowing from the sluice as at present. Do you imagine there would then be any difference in the behaviour of the water on reaching the lower ground from that which it now exhibits?"

"Oh, certainly," cried Tom; "it would fall with a great dash and a roar, and perhaps would shake the ground, so that one might even feel this bridge trembling; there would be a great boiling and bubbling action below; some of the water would be dashed into spray; and the stones at the bottom would soon become worn."

"I declare," struck in Miss Villiers, "Tom is getting quite an adept at description. His account of what would happen if the water here splashed down unimpeded by a wheel, actually reminds me of a passage in this volume, which I was reading while you and Tom were talking to the workmen."

"I see," said Mr. Seymour, "you have brought a volume of your favourite poet with you. Well, will you read to us what the bard of 'The Seasons' says about a waterfall?"

Laura opened the book, and read with much taste and spirit the following lines:

"Smooth to the shelving brink a copious flood
Rolls fair and placid, where, collected all
In one impetuous torrent, down the steep
It thundering shoots, and shakes the country round.

At first, an azure sheet, it rushes broad;
Then whitening by degrees, as prone it falls,
And, from the loud-resounding rocks below
Dashed in a cloud of foam, it sends aloft
A hoary mist, and forms a ceaseless shower.
Nor can the tortured wave here find repose;
But, raging still amid the shaggy rocks,
Now flashes o'er the scattered fragments—now
Aslant the hollowed channel rapid darts;
And falling fast from gradual slope to slope,
With wild infracted course and lessened roar,
It gains a safer bed, and steals at last
Along the mazes of the quiet vale.'"

"All the actions," said Mr. Seymour, "which Tom mentioned, and all those which Thomson so finely describes as produced by a fall of water, involve movements against resistances, and therefore they represent *work*—I mean, of course, work in the scientific sense—not useful work. See how the buckets of the wheel seem to *carry* the water down, and deliver it to the channel at the bottom with comparative quietness. It is thus that the wheel draws away the energy of the waterfall to perform the work useful to man, instead of allowing that energy to expend itself in producing such actions as Tom and Thomson have described for us."

"I perceive now," said Tom, "that the wheel does not utilize the whole power of work of the fall, for there are still much splashing and other useless actions."

"There is always a great and unavoidable loss of energy in water-wheels, as well as in other prime movers. Thus it happens that even with a water-wheel of the very best construction, only about six-tenths of the total energy of the head of water can be rendered available for useful work."

"What becomes of the rest?" Tom asked.

"A part you have yourself already accounted for; another considerable part is spent against the friction, or resistance to motion, presented by the bearings of the wheel itself; and some of the energy of the fall, or head of water, is invariably spent in making the water warm. For I must tell you there is a wonderful connection between heat and work: the final result of work is often the production of heat; and heat, in its turn, can be made to do work, as in the notable example of the steam-engine."

"I see now," exclaimed Tom, "t

ment I was showing to Johnny the other day, without thinking at the time anything about the philosophy of it. It was placing a penny flat upon a rough board, and rubbing quickly backwards and forwards, while it was pressed against the board by the fingers. The *work* I expended soon made my arm ache, but the coin became so hot that we could no longer touch it."

"A better or simpler illustration of the conversion of *work* into heat could not have been found," observed Mr. Seymour, much pleased by Tom's perception of his meaning, "and on our return, I shall present you with a toy which will serve to exemplify the production by heat of energy—that is, of power which can do work. But as I have been lecturing you to-day upon ideas which, though at present unfamiliar to you, are, nevertheless, those to which the highest generalizations of modern science are referred, I shall sum up what we have discussed in a few elementary propositions, the truth of which you would do well to verify in a hundred cases, instead of in only one or two."

Tom took out his pocket-book, and carefully wrote down the following statements as his father enunciated them:

1. *Whenever motion takes place against a resistance,* WORK *is done. The measure of the work is the amount of the resistance (expressed by a weight, usually in pounds) multiplied into the space (commonly reckoned in feet) passed over.*

2. *Whatever does work, or has the power of doing work, is called* ENERGY.

3. *No machine creates energy. A machine can do but the work done upon it; and it is used only for giving a convenient form to available energy.*

4. *Every body in motion possesses energy in virtue of that motion. The amount of work which it can, and must do, before coming to rest, may be found by dividing its weight in pounds by* 64, *and then multiplying the quotient by* THE SQUARE OF ITS VELOCITY, *expressed in feet per second.*

When our party had returned to the lodge, Mr. Seymour produced the toy to which he had alluded. It consisted simply of a small flask of thin hard glass, in which water could be boiled over a spirit-lamp. From the neck of the flask four glass tubes projected horizontally; the ends of the tubes were drawn out so as to form very narrow-pointed orifices; and each tube

was bent horizontally so that its orifice was at right angles to the tube itself, all the bendings being made in the same direction round the flask. An indentation in the bottom of the flask, like that seen in a common wine-bottle, enabled it to be supported on a piece of brass, forming a pivot on which it could easily move round, and a vertical wire attached to the cork kept the vessel upright, and afforded facility for its rotatory motion by passing through an eye in the stand above. When some water had been introduced into the flask, the spirit-lamp was applied, and as soon as the steam began to issue from the orifices of the tubes, which were its only means of exit, the little machine commenced to rotate in the opposite direction to that in which the jets of steam were rushing forth. But when the water was in brisk ebullition, the motion became so rapid that the four projecting tubes could not be distinguished. Tom and the rest were not a little interested in seeing that the heat of the spirit-lamp could produce so rapid a movement by this simple contrivance. Nor did they fail to perceive that the toy furnished an example of the law of action and reaction; for it was clear that the motion could not be imparted to the steam in one direction, without the force at the same time acting on the ends of the tubes in the opposite direction.

Mr. Seymour stated that this toy showed one of the very simplest arrangements by which the energy due to heat could be applied to produce motion by the agency of steam. He told them that it had been supposed by some that a steam-engine on this principle had actually been constructed by Hero of Alexandria, more than a hundred years before the Christian era. He showed an imaginary sketch of this so-called steam-engine, in which it was represented as *doing work*. The sketch was something like the annexed cut (Fig. 70), in which A represents a hollow globe, turning on a pivot at B, and at the top having an axle projecting so as to turn in another pivot above the machine. The pivot at B is supposed to be formed by the end of a pipe which conveys steam from a boiler into the interior of the globe, from which it escapes through jets at the ends of the horizontal arms, which jets are all pointed in the same direction. The strap passing round the pulley attached to the axle indicates the method by which the energy of the machine might have been transmitted to the interior of the building.

Mr. Seymour gave Tom and John yet another toy in which

heat was the cause of motion. This was the well-known little model of a steamship, in which a spirit-lamp raises steam in a miniature boiler, and the steam finding vent in a jet directed backwards, propels the little boat along the water. It was pointed out, by Tom himself, that this was another case of action and reaction, and that the little steamer moved through the water by virtue of the same principle as was manifested in the flight of the rocket. Mr. Seymour took occasion to remark that they would deceive themselves very much if they forgot for a moment that the law of action and reaction was in operation just as much in cases where motion occurred in one direction, as in those where motions in opposite directions were produced. The cistern from which a jet of water flowed was subjected to as much backward pressure as the issuing water was to a forward pressure.

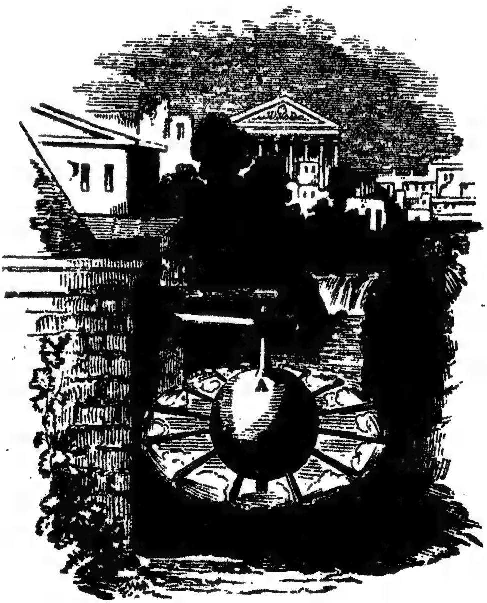


Fig. 70.

CHAPTER XVI.

They parted—ne'er to meet again !
But never either found another
To free the hollow heart from paining.
They stand aloof, the scars remaining,
Like cliffs which had been rent asunder ;
A dreary sea now flows between ;
But neither heat, nor frost, nor thunder,
Shall wholly do away, I ween,
The marks of that which once hath been.

FOLLOWING the conversation just related came an interval of many days, during which the philosophical recreations of our young friends were entirely suspended; and though this period did not pass without leaving behind it many pleasing recollections, the occasions of these may find no detailed record in these pages. Suffice it to mention that interesting excursions to places of scenic attractions or of historical associations, entertaining visits to families in the neighbourhood, little reunions for croquet parties, archery contests, flower shows, *fêtes*, and the like, agreeably diversified the next two or three weeks, and afforded

to Miss Villiers and the Seymours a round of varied enjoyment and healthful recreation.

During this period the acquaintance between Mr. Goodenough and Major Barker was ripening into friendship. The major visited the vicarage, and inspected the reverend antiquary's collection; the vicar called at Ivy Cottage, and was shown some Indian coins and other curiosities, which furnished occasion for much pleasant and profitable conversation. Mr. Goodenough was greatly charmed with the major's old English plainness of manner, and with the outspoken honesty with which he freely expressed his opinions. He wasted few words in the ordinary phrases of formal compliments; and although he never violated the rules of good breeding, he would not go the length of sacrificing sincerity at the shrine of politeness. Possibly, had the gallant officer been a more self-asserting man and a better courtier, he would have retired from the army with some higher rank than that of major.

In the first conversation with the vicar, Major Barker had briefly alluded to certain circumstances which had had a powerful influence over his life; and though these topics were not again referred to until some time afterwards, it will now be necessary to make our readers acquainted with an earlier page of the major's history by a retrospective glance at events which occurred more than thirty years before. At that epoch Edward Barker, then a very young man, had become fascinated by the charms of a young lady of great personal attractions, winning manners, and amiable disposition. The short period during which he was thrown into her society sufficed to implant in his breast a deep-seated and romantic passion; and this sentiment had entirely possessed his mind before he discovered that his feelings could not be reciprocated, for the object of his admiration had fixed her affections on another. The state of mind produced by this discovery may be imagined but not described. Edward, after a farewell interview, at once quitted the scene of his bitter disappointment, resolving to leave England and seek refuge in a foreign land from aught that could recall his fond illusive dream. He sought not to know even the name of the favoured swain who was to possess the happy fair. This circumstance is not so surprising, as that the space of a few weeks should have sufficed to lay the foundation of a feeling which, in a manner, lasted for a lifetime. For this lost love, though but a youthful romance

of six weeks' duration, became, by the light of memory and the play of fancy, a glorious ideal to which passing impressions were compared and ever found wanting. Every reader must have experienced some of the illusions, in which, favoured by time and distance, the bright beams of the imagination can irradiate with gorgeous hues even dull and commonplace actualities;—how much more splendid must, then, the vision be when the object contemplated appears like a realization of youthful hopes, illumined by

> The light that never was on sea or land,
> The consecration and the poet's dream!

Here, then, is a little touch of romance in the history of the matter-of-fact, blunt-spoken old bachelor, the heavy cavalry major. But there was another sentiment of affection of a wholly different kind—more real, perhaps, and certainly extending over a far longer period of his existence, from which Edward Barker was fated to suffer. We have already learned that he had an only sister, and to this sister he had been tenderly attached up to the period of his leaving England. There had ever been the most cordial, deep, and complete sympathy between brother and sister, until the mischievous little god, who sometimes so wantonly disturbs the peace of families, gave occasion for a deep alienation. Edward's sister had pledged her troth to a man against whom he had conceived a rooted dislike—not on account of any unworthiness of character or conduct on the part of the aspirant himself, but because his social position was judged to be so inferior to that of the Barkers, that the affair would be looked upon by their rich uncle and others as a *mésalliance.* Upon this view of the case Edward volunteered some free commentaries and administered some unwelcome advice; and this altogether failing in its intended effect, he assumed a dictatorial tone of authority—fraternal, perhaps, but certainly indiscreet. This was sharply resented, and a quarrel ensued, characterized by that bitterness and irreconcilability which so often mark the quarrels of relatives. On the brother's part it was not changed affections, but rather wounded pride, which long maintained this breach. Before he left England he declared that, should his sister fulfil her engagement, he would disown her for ever. They parted in anger. He afterwards, however, wrote from India a long letter, expostulating, and entreating his sister to renounce her project, and come out to him in India;

and concluding by a renewed and solemn declaration that should she persist, she should see his face no more, and that she should be to him as one dead. This fraternal opposition proved in vain; for, a year after Edward's departure, his sister married the man of her choice. The brother, on receiving this intelligence, carried his threat into effect by breaking off all intercourse with his only relative. He himself, perhaps, suffered the more in consequence of this resolve; but pride prevailed over affection. The union for which his sister had thus sacrificed her brother's regard, though alluded to by the major in his conversation with the vicar as an unfortunate marriage, was not so from her own point of view, and was, indeed, a tolerably happy one. But it did not last long; for a few years afterwards, a cold and formal note was received by Edward announcing his sister's decease, and merely stating that she had left one child—a boy. It would be useless to attempt to paint the conflicting emotions which raged in Barker's breast on the receipt of this intelligence. He felt prompted at one time to write to the bereaved husband, to learn all the particulars; and again his pride prevailed, and prevented him from carrying out this intention. He was long tormented with agonizing regrets for what now seemed, when it was too late to be atoned for, unfeeling and harsh conduct towards one to whom he ought, under any circumstances, to have given sympathy and support.

Filled with such emotions, he once wrote a brief letter to the father of his sister's child, to ask about the boy. He received but a curt reply, for he had to deal with a man whose pride was scarcely inferior to his own. This reception of his advance renewed his old hostility, and no further intercourse was attempted on either side. Edward continued to reside in India, and never set foot in Europe until about twelve months before our story opens. He had become a rich man, for his frugality and the regular and unostentatious life he led not only enabled him to leave untouched the legacy his uncle bequeathed to him, but, by some fortunate investments in tea plantations and other enterprises, he had so far increased his substance, that he was now a man of really considerable wealth.

He returned to England with expectations of finding satisfaction and contentment in breathing again his native air. But disappointment ensued. Everything seemed changed somehow; everything appeared altogether different from what he had left,

and from what he had hoped to find again. There was no home to which he could betake himself, and wherever he went, he felt there was something lacking. In Cheltenham, Brighton, London, and now in Overton, he successively lived without attaining the contentment he expected. His thoughts often recurred to his sister's child, now grown to man's estate; and there not seldom were moments when he would have clasped to his heart the nephew he had never seen, had the latter but opportunely presented himself. Thus, under the plain speech and unceremonious *bonhomie* of the major, there were concealed disappointed feelings and a vacant longing for some objects which might enlist his sympathies and engage his affections.

But it is now time to return to our youthful friends at Overton Lodge, whose heyday of existence was made glad with joyous spirits and bosoms free from care. Mr. Seymour was walking about the grounds, thinking about what pastime might furnish a theme on which to recommence his scientific lessons, when the sounds of light-hearted laughter attracted his steps towards a group of elm-trees; and there he found the children amusing themselves with a new swing which the gardener had just erected.

Tom asked his father whether the swing was not capable of yielding some philosophical instruction, and he said he should like to know why it happened that this new swing had a movement so much pleasanter than the old one.

"The swing," replied his father, "is, of course, governed by all those laws of motion and force which we have already described, and a consideration of these, as applied to the case of a suspended body, would lead us to a subject of great importance in science, namely, the *pendulum.*"

"The pendulum was discovered by Galileo, was it not?" cried Louisa.

"Perhaps it would be more correct to say," replied Mr. Seymour, "that Galileo discovered the property of a pendulous body which so admirably adapts it for use in clocks; I mean the fact that its vibrations are *isochronous*, that is, that they take place in equal intervals of time."

"There is one thing about pendulums and swings," said Louisa, "which I do not understand, and that is how it happens that the force of gravity which acts straight downwards is able to make a body move backwards and forwards across the direction in which it pulls the body."

Mr. Seymour said that he hoped to be able to explain that and other matters connected with the pendulum when they went indoors, where he proposed to set Tom and Louisa to work to discover for themselves some of the laws of the pendulum.

Tom had also a difficulty upon which he asked for some enlightenment. "It seems," he said, "as if there were something contradictory to the law of the equality of action and reaction, that I am able, when standing on the board of the swing, and without touching any other object, to cause the oscillations of the swing to become larger and larger until the ropes are nearly horizontal; and I can keep up this motion of the swing, which would otherwise soon come to rest, by merely humouring its movements."

"I well know the action to which you refer," replied Mr. Seymour; "but let us see you do it now, as I wish to call attention to your attitudes."

Tom at once mounted upon the swing-board, standing upon it, and grasping one of the ends in either hand. He then asked to be started by a slight push, and when this had been done, he, by those movements which are well known to all who have practised this species of amusement, soon caused the amplitude of the oscillations so to increase that he actually seemed to swing nearly level with the supports of the ropes. Mr. Seymour, during this exhibition, asked the rest to observe the attitudes assumed by Tom at the different periods of the oscillations. They soon noticed that in descending Tom lowered his body as if he were going to sit down, but when he came to the central position he raised himself quite upright, seeming in this way to fall and rise with the swing, which was what he meant by saying he humoured the motion. Fanny said she also could swing herself without touching anything, and by only sitting on the swing-board; and she did this, while Mr. Seymour asked her brothers and sisters to observe that it was accomplished by leaning backwards and keeping the feet down in descending, and by raising the body and the feet in ascending.

"Tom's and Fanny's movements on the swing have the same results," said Mr. Seymour; "namely, a lowering of the centre of gravity as much as possible during the descent of the swing, and a raising of it when the swing has reached its lowest point. And the effects of these changes I will presently explain to you."

When our friends had returned indoors, and were seated

round the library table, Mr. Seymour began his explanation of the swing and the pendulum by drawing a diagram like Fig. 71, by the aid of which he proceeded, in the first place, to solve Louisa's difficulty about the vertical force of gravity producing lateral motions.

"Let A B," said he, "represent a fine thread attached to a fixed support at A, and terminated at B by a small weight. You well know that the weight would hang exactly below A, so that the A B would be quite vertical, and in this condition it would be simply the plumb-line which you see workmen using when they wish to find the vertical direction. Now, suppose that the weight B is drawn a little on one side, so as to occupy the place C. Gravity is always pulling the weight vertically downwards, and we may represent this pull of gravity by drawing the vertical line C D, the direction of which will represent the direction in which gravity acts, and its length may be made to represent the amount of the force. That is, if the weight is one ounce, I may make C D measure one inch; if the weight is two ounces, I can indicate the fact by making C D two inches long—and so on. But now, before I proceed, I shall ask Tom to tell me whether gravity is the only force acting on the weight, under the circumstances considered."

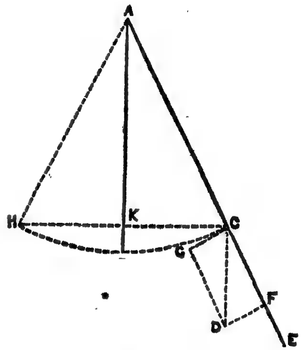


Fig. 71.

Tom was going to say it was, but he remembered that if this were the case, the weight must move downwards along the line C D. He said, therefore, that there must be some other force opposing this movement, but he did not see what caused it.

"Let us try to make this out," said his father, "by the aid of a little geometry. We will first lengthen out the line A C towards E, and from D we draw the line D F so that D F C shall be a right angle. From C and D we draw lines parallel to D F and C F respectively, and the lines so drawn meet at G; C G D F is therefore a parallelogram, and C D is its diagonal. It is proved in books on mechanics that if a line C D represents by its direction

and length the direction and amount of a force acting on a particle, the effect will be the same if we substitute for the original force two other represented in direction and amount by the two adjacent sides of any parallelogram of which C D may be the diagonal. Therefore, the lines C F and C G represent two forces into which the single force of gravity may be thus resolved. The one of these component forces which acts along C F is exactly balanced by the tension of the cord C A, according to a principle with which you are acquainted, namely, the equality of reaction to action. The other component, C G, is unopposed, and it therefore shows itself by producing motion in its own direction, for you perceive that the circular arc and the straight line C G coincide in direction at C."

Louisa confessed she did not yet understand about resolving forces along the sides of parallelograms, but she thought she had now some idea of the way in which the weight was in part supported by the tension in the string which pulled it towards A, while gravity was pulling it towards D, and these directions not being diametrically opposed, the body therefore moved in an intermediate direction, represented by C G.

"Observe, then," said Mr. Seymour, "that when the weight is at B gravitation has no power to cause motion, for the tension of the cord is then exactly opposed to it; and as the weight passes from C to B, the tension of the cord and the pull of gravity get more and more nearly into a straight line, so that the resulting force which moves the weight along the arc C B gradually diminishes, until at B it becomes nothing. Nevertheless, in accordance with the first law of motion, the velocity of the moving body is constantly increasing as it passes from C to B, and at B the velocity is at its greatest. The velocity there is sufficient to raise the weight against the force of gravity through a space exactly equal to that through which it has descended, and the weight will therefore move forward with a constantly diminishing velocity along the arc B H until it reaches H; and since at H it would be in a situation exactly corresponding with that in which it was placed at C, it would describe again the same arc in the reverse direction, returning to C, from which it set out; and the vibration would be thus continued for ever if the resistance of the air and the resistance of the cord to bending, or the friction at the point of support A, did not introduce opposing forces."

"Then, if these resistances could be done away with," exclaimed Louisa, "we should really have a case of perpetual motion?"

"Certainly," said her father; "and, as I already mentioned to you, by removing these disturbing influences as much as possible, a pendulum has been made to swing for thirty hours. But I should like to ask Tom to tell us, if he can, what would be the velocity of the pendulous body when it arrives at B (Fig. 71), after having descended through the arc C B?"

"That I cannot do," replied Tom, "for it would require a long and very difficult calculation, since the amount of the impelling force is constantly changing as the body moves."

"Nevertheless," replied his father, "you ought, from our conversation at the mill, to be in possession of a principle which would enable you to solve the problem."

"The principle of *work?*" cried Tom. "I do not see how I could apply that."

"Suppose the pendulum in our diagram to be at rest, with the line hanging vertically from A. If you raised the weight to C you would have to do a certain amount of *work*."

"Yes; I should have to overcome the force of gravity through a certain space; but as the force is not uniform along the arc——"

"Never mind that: notice that when the body is at C, it is higher than it was at A by the distance K B, which we find by drawing from C the horizontal line C K. Now, the space through which the *whole effect* of gravity on the weight has been overcome is evidently equal to B K."

"I see!" cried Tom: "the *work* done would then be the weight of the body multiplied into the distance B K."

"And, like the ram of the pile-driving engine, the weight, by descending to its original level, would have regained just the amount of energy which was expended in raising it; in other words, its velocity at B would be exactly that which would suffice to raise it again to the height B K; and therefore the horizontal velocity of the pendulum at B must be precisely equal to the vertical velocity which a body would acquire in falling freely through the distance K B."

"I perceive," said Tom, "that by applying the principle of work, the question of the velocity becomes quite simple."

"Now, as the pendulous body has, when it arrives at B in its

descent along the arc C B, a certain amount of moving energy, which must be expended in doing work before it can come to rest at H, it follows that this energy will just suffice to carry the body to H, thus making the work it does exactly equal to that which has been done upon it. And this equality of work is absolutely true with the actual pendulum, as with the imaginary one, because the energy expended in overcoming the resistance of the air, and the friction of the point of support being withdrawn, there is not left the amount which suffices to carry the body to H; and as this effect continues in every vibration, the amplitude of the oscillations becomes less and less until the pendulum finally comes to rest. But observe that it comes to rest only after it has expended, in overcoming the resistances I have named, an amount of work exactly equal to that which was originally done upon it, when the gravitating body was raised by being drawn aside, so as to start the oscillatory movement."

Tom and Louisa both believed that they quite understood this part of the subject, and begged their father now to explain the power which a person on the swing has of increasing the amplitude of the oscillations.

Mr. Seymour reminded them that in that exercise the centre of gravity of the body was always raised as the swing passed under the points of support, by the movements which they had noticed. He then sketched the diagram shown in Fig. 72, and proceeded as follows:

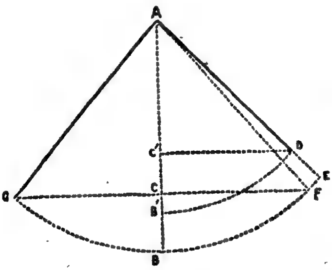


Fig. 72.

"After the discussion of the centre of gravity we had lately, I need scarcely say that we may consider the whole of the action of gravity as taking effect there. Let A represent the point of suspension of the swing, and let G be the common centre of gravity of the person swinging, and of the seat, &c. We may suppose that it is Tom's centre of gravity when he was, as he said, humouring the motion by ducking down at the highest point of the oscillation, and so continuing during the descent to the central position at B, along the arc G B. How

Tom's centre of gravity came to be at the height G we need not inquire, but it is certain that when it arrives at B it has acquired a velocity which will carry him vertically upwards to a height equal to B C. At this part of the oscillation, and possessing the energy I have indicated, he draws himself up, so that his centre of gravity is raised to B′; but the horizontal velocity it has acquired in descending from G to B will raise it a vertical height B′ C′, equal to B C, that is to D; and as it is then moving in the arc B′ D of shorter radius G B, the angle C′ A D will necessarily be greater than B A G—that is, the extent of the oscillation will be increased by the angle F A E. Arrived at the limit, Tom again ducks down, and thus brings his centre of gravity to E, and so the cycle of operations is repeated, the amplitude of the oscillation augmenting until the increasing resistances put a limit to further augmentation."

Mr. Goodenough arrived at this moment, and was informed of the subject of the lesson which was going forward. The conversation then turned upon the remarkable property of the pendulum which makes it so useful for measuring time, and for various accurate scientific observations.

"Although the oscillations of a pendulum," said Mr. Seymour, "as its motion is gradually weakened by the resistance of the air, take place over arcs progressively smaller, yet it is found, if the amplitude of the oscillations is not very great, the time occupied in each vibration is practically the same whether the arc be smaller or greater. I think you ought to convince yourself of this fact by a few experiments."

Mr. Seymour produced a small leaden bullet, to which a very fine thread had been attached; and when this was suspended and made to oscillate, it was easy to find, by counting the number of vibrations which took place in two successive half-minutes, that the number scarcely varied, although in the last interval the oscillations were very small indeed compared with those counted during the first interval.

"This is very curious," said Louisa, "and quite different from what I should have expected; for I should certainly suppose that the quicker movements which the bullet had when you first set it in motion would occupy less time than the slower vibrations at last. But, of course, the space traversed in the wider swings makes the actual velocity greater. I wonder how Galileo first made this discovery?"

"It is related," replied her father, "that Galileo was in the cathedral at Pisa, when his attention was attracted by the motion of one of the chandeliers depending from the ceiling; and by attentively observing it, he soon noticed the uniformity in the periods of oscillation."

"His mind could not, I fear, have been concentrated on his devotions, or he would not have noticed such a trifling circumstance as the swinging of a chandelier," remarked the vicar.

"I cannot think the circumstance was at all trifling," replied Mr. Seymour, "if we regard its results. And the incident itself seems to me a very striking one. That one man of science, who only, of all the prostrate crowd of worshippers, was unconscious alike of the solemn chants, the sublime strains of the organ, the clouds of incense, and the vestured priests, should then and there be intently and calmly observing a simple phenomenon of nature, becomes a very notable event, when we remember to what these observations led. This was one of the most important discoveries of Galileo, and it was one of his earliest, for at that time—about the year 1582—he was only twenty years of age. You may wonder that a law like this, which you have yourselves just now so easily verified, should have been hid from men's knowledge for so many ages. Pendulous bodies must have been continually before people's eyes, but the discovery waited for the man of observing mind with thoughts engrossed by kindred subjects."

"Does the period of vibration," asked Tom, "depend at all on the matter of which the pendulum is composed? I mean, would a ball of ivory or any other substances give exactly the same results as this leaden bullet?"

"We have already learned," replied his father, "that gravity acts upon all bodies alike; and this has been found to be confirmed by pendulum experiments with all manner of substances, which give invariably identical results, when the disturbing influences of the resistance of the air, &c., have been withdrawn. Galileo found, by suspending balls with threads of different lengths, that the time occupied in the vibration increases with the length of the thread, but by no means in simple proportion."

"In what proportion, then, papa?" asked Louisa.

"My dear, I cannot do better than set you to address your question to the facts themselves, or, in Bacon's words, 'to interrogate Nature by experiment.' But to simplify the matter a

little, make the suspending cord, first, $9\frac{3}{4}$ inches long from the point of suspension to the centre of the bullet, and count the number of oscillations per minute; then count the number with the cord 39 inches long; and, lastly, we will suspend the bullet in the hall by about 13 feet of thread."

The young people at once proceeded to perform these experiments, and the following were the results: Cord $9\frac{3}{4}$ inches long, 120 oscillations per minute; 39 inches long, 60 per minute; 13 feet long, 30 per minute.

"That is," said Mr. Seymour, "the shortest performs an oscillation in half a second; the next in a second; and the longest in two seconds. The times of the oscillations are, therefore, if we take *half a second as unit*—1, 2, and 4. But let us write these in a column, and put opposite to each the length of the cord. Looking at these lengths, you will perceive that the second is four times the first, and the third four times the second; so that here, if we make $9\frac{3}{4}$ inches the unit of length, we shall find the respective numbers, 1, 4, and 16, to express the respective lengths of the cords; and it is easy to see that these figures are exactly the squares of the times, or, in other words, the periods of the oscillations are proportional to the *square roots* of the lengths of the pendulums."

These figures, which when arranged in the manner suggested by Mr. Seymour, formed the following table, in which the law is easily recognized:

Time of vibration in half-seconds.	Length of threads in inches.	Relative lengths of threads.	Square roots of relative lengths of threads.
1	$9\frac{3}{4} \times 1 = 9\frac{3}{4}$	1	1
2	$9\frac{3}{4} \times 4 = 39$	4	2
4	$9\frac{3}{4} \times 16 = 156$	16	4

Tom and Louisa were much pleased to find that they could thus easily verify the experiments of the great philosopher of Pisa, and they said that they were sure they would never forget this law of the pendulum, which they had in this way re-discovered for themselves.

A difficulty, however, arose in Louisa's mind. She had one of those instruments called *metronomes*, which are sometimes used to mark time in performing pieces of music. The construction of these instruments being probably familiar to most readers, we need only say that a short metallic rod oscillates

about a fixed centre, and the rapidity of the oscillations are changeable within a great range by shifting a movable weight which slides on the bar. Louisa perceived that this oscillating bar was really a pendulum, and her difficulty consisted in seeing how the number of oscillations could in this case be governed by the law they had just verified.

Mr. Seymour then stated that in the experiments they had just tried, the oscillating body very nearly realized the case of what was termed the *simple pendulum*, and this was explained to mean that there should be an extremely small gravitating mass at the end of a weightless string. A body of any shape would form a pendulum if properly suspended. This was illustrated by means of a planed lath of deal, which Mr. Seymour made to oscillate by suspending it on a pin passed through a hole bored near one end.

"It will hardly be necessary for me to point out," said Mr. Seymour, "that every particle of this lath is oscillating about its centre of suspension with the same period of vibration. But you know now that if the parts of this rod were detached from one another, these would each swing in its own period according to its distance from the centre, by the same law you have demonstrated in the case of the leaden bullet. As, however, the rod must swing as a whole, it is evident that most of its parts have to oscillate in either a longer or a shorter period than they would if free. And as we know those nearest the centre of suspension would move fastest and those farthest from that centre slowest, it is manifest that there must be some intermediate point in the rod which is actually oscillating with the same period it would have if detached from the others. Let us try to find the position of this point by experiment. In order to do this, take the suspended bullet and vary the length of the thread until you find the bullet swings in exactly the same period as the lath."

After a few trials Tom had succeeded in obtaining a nearly perfect *isochronism* between the two vibrating bodies. The distance of the centre of the bullet below the point of suspension was then measured, and found to be about two-thirds the length of the lath. Mr. Seymour said that the lath was an example of the *compound* pendulum, and that its period being identical with that of a simple pendulum as represented by the bullet, the latter might be termed the equivalent simple pendulum. They could now mark on the lath the exact point which vibrated with its

natural period, if he might so express it, while the lath as a whole vibrated as if its entire mass were collected there. The centre of gravity of the lath having been found by a method already familiar to the reader, a straight line was drawn through it from the point of suspension and continued downwards. On this line the length of the equivalent simple pendulum was measured off from the point of suspension, and the point so obtained was marked on the lath. This point, Mr. Seymour said, was called the centre of oscillation, and it had a remarkable property which he would show them. He accordingly bored a hole through the lath at this point, and when he made this the point of suspension it was found that in its inverted position the lath vibrated in exactly the same period as before, the times being tested by a comparison with simple pendulum as before. This interchangeableness of the centres of suspension and of oscillation in a compound pendulum was a property of great importance, for it permitted the equivalent length of a compound pendulum to be ascertained; and all real pendulums were always compound pendulums. Mr. Seymour then referred to some of the uses of the pendulum for scientific purposes other than measuring time, as, for example, that by it the velocity of falling bodies, or the acceleration produced by gravity, could be ascertained with great exactness, and consequently the oscillations of the pendulum furnished the most perfect measure of the force of gravity which we possessed. Pendulum experiments in various parts of the world have shown that the intensity of gravity varies over the surface of the earth, partly on account of its figure being not spherical, but flattened at the poles, and partly for other reasons. The following are some values of the acceleration due to gravity; that is, they express in feet the velocities which would be impressed in one second on bodies falling freely:

At the equator	32·088
In latitude 45°	32·171
At London	32·182
At the poles	32·253

"But to return to Louisa's question about the metronome," continued Mr. Seymour; "I may state that although our experiment with the lath shows that its centre of oscillation falls within the length of the body itself, it is easy to construct a pendulum so that this point shall be far beyond the limits of the pendulous body. To illustrate this I might take a light

uniform rod of wood—this lath, for example—and make the axis of suspension at the centre of its length. In this case, we should find that the body would show no tendency whatever to oscillate. Also, if I were to attach equal weights to each end of the rod, these being at the same distance from the centre, the rod so weighted would not oscillate; it would rest indifferently in any position, being supported at its centre of gravity. But if I were to increase one of the weights by a very small amount, it is evident to you that that end of the rod would preponderate, and the whole would then oscillate about the point of suspension, until it came to rest with the heavier weight vertically below that point. And it is not difficult to see that the oscillations would be wholly due to that portion only of the lower weight by which it exceeds the other. Also, if we made this difference small, it is plain that the motion would be slow, for it would be a case of a small force applied to a large mass. In other words, the centre of oscillation would be at a great distance from the centre of suspension, and I might make this distance as great as I pleased by making the difference of the two weights sufficiently small. A similar result would take place if, the weights remaining equal, I were to place one of them a little nearer than the other to the axis of suspension. The centre of gravity would then fall a little way below the point of suspension, and the motion would, as in the former case, be slow, and might be made as slow as we please. The adjustment of the metronome is made by sliding a weight along the upper part of the vibrating rod, the period of the oscillation being increased or diminished by raising or lowering the weight above the centre of suspension. By thus bringing the centre of gravity nearer to, or farther from, that point, the centre of oscillation may be placed at a greater or less distance, and the pendulum made to oscillate with a longer or shorter period accordingly."

Tom now asked how they could construct a pendulum which would vibrate seconds exactly.

"The length of the *simple* pendulum," said Mr. Seymour, "which in the latitude of London would make 60 vibrations per minute, is 39·139 inches; but the pendulum which would vibrate seconds in another latitude would be of a different length. Thus, at the equator the seconds pendulum is 39·021 inches long, while at Spitzbergen it is 39·215 inches. If you

suspend this leaden bullet by a thread so that its middle point is 39⅛ inches below the point of suspension, you will find it will nearly vibrate seconds. But as this is still a really compound pendulum, you could ascertain the *exact* length only by a mathematical calculation. Practically, the lengths of the pendulums employed in clocks are determined by trial with others of known correctness, the final standard being an astronomical one, founded on the diurnal revolution of the earth."

"And," said Tom, "is it quite certain that the earth will always rotate at precisely the same rate? and should we know if any change took place in this respect?"

"It is beyond doubt," said Mr. Seymour, "that if we must have an absolutely invariable standard of time, we must look to something else than the earth's rotation. Laplace, the celebrated French mathematician, once made a calculation founded on ancient observations of eclipses, with the result that the period of the earth's rotation about its axis could not have altered its period by more than one ten-millionth part for the last twenty-six centuries. But not long ago an error was discovered in this calculation, and the corrected result shows that the period of rotation has undergone a slight augmentation since B.C. 720. The estimated amount of the augmentation is very small, not exceeding the one thirty-second part of a second; but in the progress of ages this continual retardation of the earth's velocity will doubtless become sensible."

"But," cried Louisa, "is not the rotation of the earth precisely one of the instances of the eternal uniformity of motion when there is no friction or other disturbing cause to interfere with it?"

"It so happens, my dear," replied her father, "that in the case of the earth there is friction, and also other causes which it is known must operate to retard the velocity of rotation. The friction is occasioned by the tides, for the earth rotates, as it were, within masses of water heaped up by the moon's attraction—I mean, of course, the two tidal waves, under each of which the surface of the earth successively passes every twenty-four hours. Now, as this cannot take place without a certain amount of friction, there is a constant drain on the energy of the earth's rotation. Another cause of retardation may be found in the meteorites, which fall upon the earth from interstellar space."

"You are alluding," said Tom, "to those great lumps of iron, of which we saw some specimens at the British Museum, and which you then told us fell from the sky. I quite remember thinking what enormously heavy lumps they were."

"Heavy as they are," replied Mr. Seymour, "the mass of even the largest is excessively small compared with that of the earth. Yet you are well aware that the earth cannot impart its own motion to even the smallest of these without losing an equivalent of that motion. This cause of retardation of the earth's motion tends, at the same time, to accelerate the vibrations of the pendulum, since the meteorites add to the earth's mass, and therefore to the force of gravity at its surface. We must remember that these meteorites have been falling upon the earth in all ages; and of those which have fallen in historical times probably all but an infinitesimal proportion have fallen unobserved and unrecorded. Again, a quite recent discovery shows that this kind of accretion to the earth's mass may be continuously going on from hour to hour in a very unobtrusive way. I refer to an observation which has lately been made that goes to prove that ferruginous particles, in all probability the products of the combustion and dispersion of meteoric masses of iron in the higher regions of the atmosphere, are continually settling down upon the earth's surface. In rainwater collected in localities remote from all human habitations, in the snows gathered from the slopes of the loftiest Alps, and from deposits settling on horizontal surfaces exposed under conditions where no artificial products can reach them, minute particles, attractable by the magnet, can be obtained in such abundance as to prove that this iron rain is being quietly and continuously precipitated over the whole surface of the globe. But as we have pursued this digression sufficiently, I will return to our immediate subject by asking you to notice an interesting property of the centre of oscillation, which we can illustrate by our suspended lath, in which we have already determined that point."

Mr. Seymour set the lath swinging, and showed that when it was allowed to strike against an obstacle placed opposite to the centre of oscillation, the result was a dead blow; but when the collision occurred at some other point of the length, a kind of jar or tremor was set up in the vibrating body. In some of the experiments this irregular action had the effect of jerking out of

its place the pin which supported the lath. When the blow was delivered at the centre of oscillation, the impetus appeared to be evenly balanced, as if the moving force were collected at that point. "For this reason the point is," Mr. Seymour explained, "in such cases called the *centre of percussion.*"

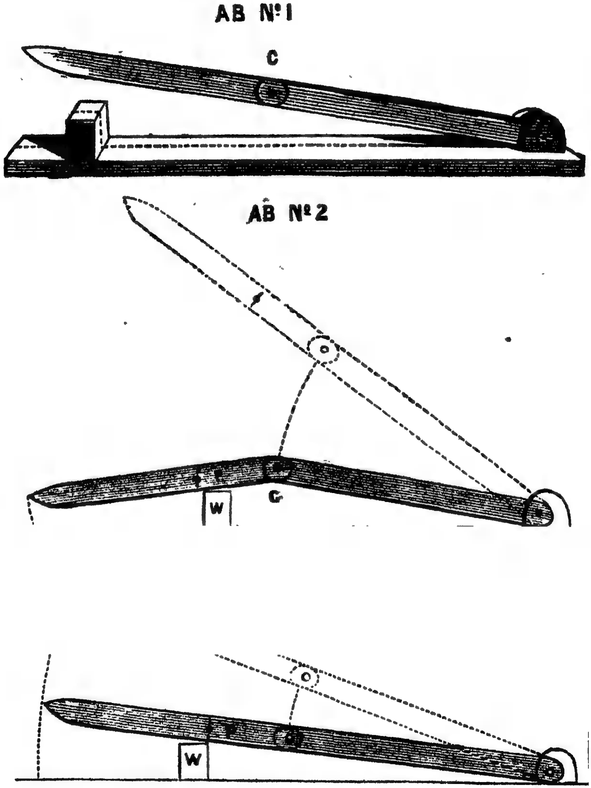


Fig. 73.

He further illustrated this subject by a model (shown in Fig. 73), in which two laths, jointed as at C in the annexed figure,

were intended to represent the blade of a sword turning about a centre at K. When this was allowed to fall by its own weight from the position shown by the dotted lines upon a block of wood, W, the effect varied according as point of impact was related to the centre of percussion, P. When P was beyond the edge of the block on which the wooden sword impinged, as in No. 2, the elbow-joint became bent as in that figure. When the block was beyond the centre of percussion, as in No. 1, the joint became bent upwards. But when the place of contact corresponded with P (No. 3), then the pieces were not deflected at all.

It was pointed out that in consequence of this property, the effect of a blow given by a stick or by a sabre would be greatly increased if it were so delivered that the weapon should encounter its object near the centre of percussion. The position of this point would, of course, be influenced by the distribution of mass in the weapon, and the arm of the person who employs it.

Tom said that in the exhibition of swordsmanship which he had once witnessed at an athletic festival, he would doubtless have perceived illustrations of these principles if he had then been acquainted with them. He described the strength and adroitness there displayed by a cavalry soldier, who at a single stroke of his sabre completely cut in two the carcass of a pig, in the manner shown in the annexed figure (Fig. 74).

Fig. 74.

CHAPTER XVII.

> Delightful task! to rear the tender thought,
> To teach the young idea how to shoot,
> To pour the fresh instruction o'er the mind.

NEXT day, when Mr. Seymour found Tom and his brother playing at marbles on a smooth piece of ground, he asked Tom to explain why a marble always turns round as it moves along.

"I suppose," said Tom, "it depends upon the motion which I give it by my finger and thumb as it leaves my hand."

"You can doubtless thus impart a spinning motion to your marble; but I fancy you would be quite unable, if you tried ever so much, to make the marble proceed along the ground without revolving."

"I have sometimes, indeed, tried to do that," said Tom, "but I found that even when the marble was pushed along with a flat piece of wood, it would roll."

"Then it is clear that the rotation in other cases is not due to the action of your fingers in projecting the marble. I think a little consideration will show you that if the marble is projected without a rotatory motion, it must acquire one the moment it touches the ground. For the contact of the lowest part of the marble with the ground will check its velocity, while the upper part, not impeded in this way, will be urged forward at its original velocity in obedience to the first law of motion. The result will be that a rolling motion will be set up."

"But do you remember that I told you a few days ago," said Mr. Seymour, "that by giving a revolving body a peculiar *spinning* motion, certain effects were produced, which I should, on some future occasion, take into consideration?"

"To be sure I do," replied Tom.

"Well, then, attend to me."

Mr. Seymour took a marble, and placing it on the ground, gave it an impulse forward by pressing his forefinger upon it: the marble darted forward a few paces, after which it rolled back again.

"That is most extraordinary!" cried Tom. "The marble came back to your hand of its own accord, as it were, without having met with any obstacle."

"And you, no doubt," said Mr. Seymour, "regard it as contrary to the well-known law that a body once put in motion, in any direction, will continue to move in that direction until some foreign cause oppose it."

"It really would appear so."

"It is, however, far otherwise: the force which I imparted to the marble gave it two kinds of motion; the one projecting it forward, the other producing a rotatory motion round its axis in a direction opposite to that which it would usually assume by friction against the ground, and in the same direction in which a marble rolling towards me would rotate: the consequence was that when the forward motion on account of the friction of the marble on the ground was destroyed, the rotatory motion continued, and by thus establishing an action in an opposite direction, caused the marble to retrograde. If, however, you will fetch Rosa's hoop, I will demonstrate the fact on a larger scale."

Tom accordingly produced the hoop; and Mr. Seymour projected it forward, giving to it at the same instant a spinning motion in an opposite direction. The hoop proceeded forward

to a certain distance, when it stopped, and then ran back to the hand.

"I have a new toy for you," said Tom's father, "and one which will not only exercise your skill, but will serve to illustrate for us certain remarkable effects produced by rotation."

Mr. Seymour led the way to a part of the grounds where there was an open space of some extent, and then produced a sling. This toy consists, as most readers are doubtless aware, simply of an oblong or rather lozenge-shaped piece of leather, to each end of which a strong cord is attached. The sling is used by placing a stone in the piece of leather, passing one of the fingers through a loop formed in one of the ends, and then holding both cords between the forefinger and thumb so that they are of equal length; the stone is whirled very rapidly round, and when the cord is let go, the stone flies off with amazing velocity.

This feat Mr. Seymour then exhibited to the juvenile party, Louisa and her sisters having joined the others, and they were greatly astonished at the distance to which a stone could thus be hurled.

The children now proceeded to amuse themselves with the sling. Louisa challenged Tom to a trial of skill. She fancied that she could hurl a stone with greater accuracy than her brother; but after several contests she acknowledged herself vanquished, for Tom had succeeded in striking the trunk of a tree at a considerable distance, while his sister was never able to throw the stone within several yards of the mark.

"Well done, Tom!" exclaimed Mr. Seymour; "why, you will soon equal in skill the ancient natives of the Balearic Islands!"

"And were they famous for this art?" asked Louisa.

"With such dexterity," replied her father, "did they use the sling, that we are told their young children were not allowed any food by their mothers except that which they could fling down from the beam where it was placed aloft. I fancy, however, Tom, that you would become very hungry before you could strike an object in yonder poplar."

"At all events, I will try," said Tom.

He accordingly whirled round his sling and discharged its stone, which flew forward with great velocity, but in a direction very wide from the mark at which it was aimed. In the next moment a violent hallooing was heard: it was from the vicar,

who had narrowly escaped being struck by the falling stone, as he was making his way through the grounds.

"My dear Mr. Goodenough," cried Tom, running towards the vicar, as the latter emerged from the shrubs which had hitherto concealed his approach, "I sincerely hope you have not been struck?"

"Oh, no; I have fortunately escaped without hurt. But what new game is this which is now engaging your attention? The sling, I see. It seems, then, that I have been in great danger of meeting the fate of the giant of Gath."

Mr. Seymour said he was about to explain the scientific principle of the sling, and he suggested that the vicar might be able to afford them some information as to its history.

"The art of slinging," replied the vicar, "is of the highest antiquity, and the most amazing skill appears to have been attained by Asiatic nations in the use of the sling as a weapon. It was well known and practised in Europe at a very early period, and our Saxon ancestors appear to have been very expert in hurling such missiles. But pray, Mr. Seymour, proceed with your scientific explanation."

"What we have just seen," Mr. Seymour began, "is simply a result of those laws of motion with which you are already acqainted. The effects here are, however, sufficiently remarkable and interesting to make it worth our while to examine them in detail."

"Are there not certain special forces at work?" asked Louisa, with some surprise. "I am sure I have read that circular motion is always the result of two forces, called the *centrifugal* and the *centripetal.*"

"Your ideas, my dear," replied her father, "as to the existence of some special and peculiar forces concerned in causing a body to rotate about a centre, are the result of the error into which the readers, and sometimes also the writers, of popular scientific treatises are apt to fall. I allude to that very common error of supposing that for every term which custom or convenience has introduced, there is some corresponding and distinct thing existing in nature. The seeming tendency of a body revolving in a circle, as the stone is forced to do in the sling, is only an instance of the operation of the first law of motion; and since, when the stone is twirled round, it is constantly changing its direction instead of proceeding in a straight line, there must

be some impressed force at work. Now, let us consider what is it that prevents the stone from obeying the first law."

"The leather hinders the stone from flying away," cried Tom, "and the pressure on the leather causes a pull on the string, which is tightly stretched in consequence."

"Yes," said Mr. Seymour, "it is the tension of the cords which retains the stone in its circular path, and that tension is itself equal, by the law of equality of action and reaction, to the resultant force tending to withdraw the stone directly from the centre of rotation. But observe that when the stone is liberated, it does not fly away in the direction of the prolonged radius of the circle, but in the same direction on which it is moving at the moment of its liberation, namely, along a *tangent* to the circle."

"Pray what is meant by a *tangent?*" asked Louisa.

"A tangent, my dear girl, is a straight line drawn so as just to touch the circumference of a circle without cutting it even if prolonged. The tendency of the revolving stone in our sling to obey the first law has been sometimes described as producing a *tangential* force; but what we have chiefly to study in these cases of bodies constrained to move round a centre, is the resultant of this tangential force, which must be opposed by an equal force drawing the body to the centre of rotation. Since the body would, if no impressed force acted upon it, move along the tangent, and would by so doing withdraw itself from the centre round which it revolves, there must be a portion of this force resolved in the radial direction; and it is this to which the name of *centrifugal* force has been given, and which is that opposed by the tension of the cords in the case of the sling. But, now, here is another example of a body constrained to move in a circle. I lay this wooden hoop flat on the ground, and taking Rosa's ball, I cause the ball to go round and round the inside of the hoop. You see there is here no connection whatever between the body and the centre of the circle in which it is revolving; yet it is convenient to employ the terms *centrifugal* and *centripetal* to express briefly the results of the operations of the laws of motion in this case. Thus, for instance, while the ball is running briskly round the inside of the hoop, I suddenly raise the latter—away goes the ball in quite a straight line, which is a tangent to the hoop at the précise point at which the ball escaped. Now, this tendency of the ball to escape must have

been kept in check by an impressed force, which is nothing more than the reaction of the hoop itself, but which I should not hesitate to call by the name of *centripetal*, or centre-seeking, *force*, if I were quite sure that my hearers would not suppose that the name implied anything more than what I have just stated."

Louisa assured her father that there was now no danger of her mistaking the nature of the facts expressed by these terms. Mr. Seymour then said that he would give them some other illustrations of the effects of centrifugal force; and accordingly Tom was sent for a common open tin can, provided with a wire handle, the ends of which were attached to opposite points in the rim. A cord was tied to the handle, and the can having been filled with water, Mr. Seymour grasping the cord at a point about three feet from the can, began to swing the latter pendulum-wise; and then rapidly increasing the amplitude of the oscillations, soon carried it round in a circle, and continue to make it thus revolve. The young spectators were at f amazed to observe that not a drop of the water was s , although the vessel was completely inverted during a pa of each revolution.

Mr. Seymour showed by another experiment the effects of centrifugal force on water. He tied a cord with three loops round a basin, and to each loop attached another cord in the manner shown in Fig. 75. When the basin had been filled with water, it was turned round so that the three cords became twisted together, and when the basin was made to rotate by allowing the cords to untwist, the rapid revolution caused the water to rise up over the brim and to be projected tangentially, as shown in Fig. 76.

Louisa remarked that this reminded her of the way in which she had seen mops dried by trundling, so that the water flew off in all directions.

"That is a very good and familiar example of the effects of centrifugal force," said her father; "but I wonder whether Tom can tell us if any centripetal force is concerned in the operation?"

"The material of the mop itself is only restrained from flying off like the water," Tom replied, "by its being connected with the handle, and the tension of these materials forms the centripetal force in this case. The water, not being solidly connected

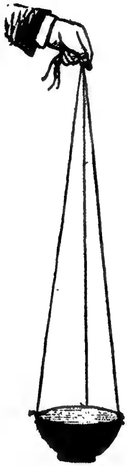


Fig. 75.

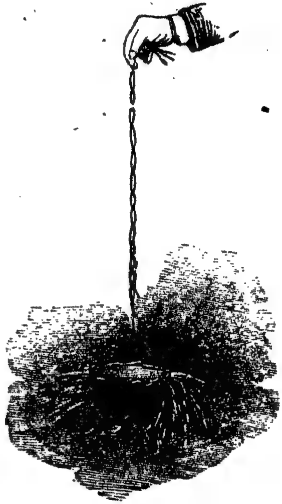


Fig. 76.

with the rotating threads, flies off tangentially, and thus the mop becomes dry."

"The same principle has been applied," said Mr. Seymour, "on a larger scale, to a machine for drying linen in laundries. The machine consists of a large hollow drum, the circumference of which is pierced with holes like a sieve. When a very rapid rotation is given to the drum, the linen, by reason of the centrifugal force, squeezes itself up against the internal curved surface of the drum, and the water is urged outwards by the same action. It is said that by a speed of 25 turns per second, linen is so thoroughly deprived of water in these cylinders, that only a few minutes' exposure to the air is required to render it completely dry. The very same kind of machine is used, for a similar purpose, in the manufacture of gun-cotton, and the application of this principle of drying may, perhaps, soon be extended to many other objects."

"I remember," said Louisa, "when we visited the pottery works at Burslem, and we were wondering how the soft clay,

which was rotated on the potter's wheel, swelled out by slight pressure into such beautiful and regular forms, you told us that it was owing to the centrifugal force produced by the rapid rotations."

"Yes, and we have also seen another notable example," said Mr. Seymour, "in the operation of glass-blowing, in which so much advantage is taken of centrifugal force. You will recollect how constantly the workmen were twirling round their iron pipes—sometimes round their own heads, and sometimes about the axis of the pipe, according to the forms they required the material to assume."

Tom now ingeniously bethought himself of a simple illustration of centrifugal force, for he took Louisa's parasol, and when he had closed it, he made the stick rotate so quickly that the ribs expanded by the centrifugal force. The annexed cut (Fig. 77) shows how this experiment was performed.

Fig. 77.

Mr. Seymour mentioned the positions necessarily assumed by the horses and riders in a circus as another manifestation of centrifugal force. In all equestrian feats in the ring, the body of the horse leans over towards the centre, and when the horse is going round at full gallop, the inclination is very considerable.

"Oh, yes!" cried Tom, "I remember seeing at Astley's a horse going round at such a speed that his position was about half-way between being upright and lying on his side, and I thought it wonderful that the man who was standing on the animal's back did not fall off, his inclination was so very great. But I see that the centrifugal force, acting horizontally, has to be resisted as well as gravity."

"That is so," said Mr. Seymour; "or let us say that gravity and the centrifugal forces have a certain resultant which is inclined to the horizon at the precise angle which horse and rider instinctively assume in order to counteract it. So that the pressure of the man's feet, even when the horse is urged to its

utmost speed, is directly downward from his head towards his feet, just as if the horse were stationary."

"When the horses went at a walking pace, I did not observe an inclination at all," remarked Tom, "though at a trot it could be seen a little."

"The amount of the centrifugal force increases as the *square of the velocity*, so that a rapid pace would produce more decided effects."

When they had gone indoors Mr. Seymour produced a toy which illustrated in a very pleasing manner the subject under discussion. It consisted of a miniature railway waggon running

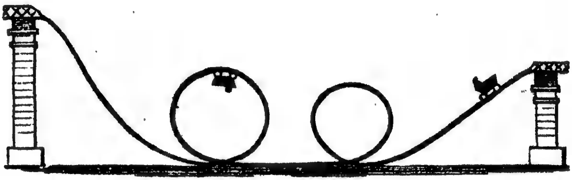


Fig. 78.

upon rails bent in the form shown at Fig. 78. The waggon, when started from the higher extremity of the rails, ran down the incline and round the inside of the curve, the velocity so acquired carrying it along the horizontal part of the rails in the centre, round the second smaller curve, and finally landing it on the stage at the right-hand side. A small article placed loosely in the carriage remained in it during the whole of this curious journey, although twice the little carriage was completely upside down.

Mr. Seymour then directed attention to the modifications of the effects of gravity by the centrifugal force produced by the earth's rotation.

"You remember," said he, "that in discussing the first law of motion, it was remarked that as the bodies at the surface of the earth do not move in straight lines, but are carried round with the globe in its diurnal revolution, we concluded that there must be a force constantly acting upon them to retain them at the earth's surface; and this force, we have seen, is that called *gravitation*. A part of the force of gravity is then balanced by

the centrifugal force: in other words, bodies at the surface of the earth do not weigh so much as they would if it were stationary. The quantity of the force of gravity thus subtracted by reason of the centrifugal force will obviously vary with the amount of the latter, and that the latter will vary according to the latitude of the place will be plain if we remember that the velocity of the surface decreases from the equator to the poles; and that although the centrifugal force increases with the decrease of the radius of rotation, the increase would be inversely proportional to the simple radius, while the decrease would be inversely as the *square* of the velocity. An easy calculation shows that at the equator, where the centrifugal force is greatest, and where it is *directly* opposed to gravity, the diminution of the latter's effect is about $\frac{1}{289}$; that is, a weight gravitating at the equator with a force of 288 pounds would weigh 289 pounds if the earth did not rotate; or, supposing for a moment that the earth's surface at the poles were at the same distance from its centre of gravity as at the equator, then a weight which would cause a spring balance to read 288 pounds at the equator, would appear to get heavier as we approached the pole, and there our spring balance would mark just 289 pounds."

"Has this result been confirmed by experiment?" asked Louisa.

"I have already told you that pendulum observation permitted such experiments to be made with the greatest delicacy, and the results have everywhere been perfectly accordant with the deductions from the theory. Of course the figure of the earth must be taken into account—for, as you know, it has not the form of a perfect sphere, but a figure more resembling the shape of an orange. There is, moreover, another circumstance relating to centrifugal force and gravity, which I may mention. At the equator the two forces are directly opposed, and the effect of the centrifugal force has simply to be subtracted from that of gravity. Elsewhere, the two forces are not directly opposite in direction, for the centrifugal force acts in the plane of rotation, while the gravitating force is directed towards the earth's centre, and the angle between these directions continually increases as we approach the poles. As a consequence of this unconformity of direction of these forces, a plumb-line must hang in the direction of the resultant. Thus the apparent vertical is not the real one, except on the equator and at the poles. For

example, at Paris a plumb-line does not point exactly downwards towards the earth's centre of gravity."

"What a curious result of this centrifugal force!" cried Louisa; "but I suppose the divergence is extremely small?"

"At the latitude of Paris, in which it is nearly at the maximum, it is considerable," replied Mr. Seymour, "for it amounts to an angle of five or six minutes, or about as much as one-fifth of the angle subtended by the moon's diameter."

"This discussion," observed Mr. Goodenough, "reminds me of a problem which was once proposed in the examination papers at Cambridge—namely, to find the elevation to which the Tower of Babel could be raised before the stones would entirely lose their gravity, or rather before the centrifugal force would balance the force of gravity. If my memory serves me, I think that under the latitude of 30°, which, I believe, is nearly that of the plains of Mesopotamia, the height would be somewhere about 24,000 miles."

Mr. Seymour then remarked that many curious effects are produced by the rotation of solid bodies, and that there were problems arising from the motions of tops and hoops which have often engaged the attention of the most profound philosophers.

"And as we seek our science in toys and pastimes," pursued Mr. Seymour, "we may perhaps find in the top some effects of the laws of motion altogether different from any we have yet studied. Besides, as the top is by no means a toy of yesterday, Mr. Goodenough may have something to tell us about its ancient forms; and I know both Tom and John will be most interested listeners, as the top was a favourite amusement of Tom's, and I often see Johnny whipping his top with vigour."

"I rejoice to find that he engages in so classical a pastime," said the vicar. "The great Mantuan bard did not consider the top a subject beneath the dignity of his muse; and the *volitans sub verbere turbo* of Virgil certainly referred to the whip-top; and what description can convey a better idea of the eagerness and zest with which youth engage in active sport than that of Virgil?—

> "'Ille actus habena
> Curvatis fertur spatiis; stupet inscia turba,
> Impubesque manus, mirata volubile buxum:
> Dant animos plagæ.'"

"May I ask," said Mr. Seymour, "whether the top was introduced into this country by the Romans?"

"It is quite possible," replied the vicar, "that the toy was known in these islands before Julius Cæsar landed on our shores; but if not, there can be little doubt that the British youth would soon observe and imitate the pastimes in which the children of the Latin colonists must certainly have indulged. Figures of boys whipping their tops appear in the margin of manuscripts of the fourteenth century, and these show that the form of the top was the same as now. But a few days ago I came across a curious anecdote of Prince Henry, the eldest son of James I., and I transcribed this in the original spelling, in order to show it to you when the top became the subject of your papa's scientific discourses."

Here the vicar took from his pocket-book a scrap of paper, which he handed round for the inspection of the party, who read thereon as follows:

"The first Tyme that he the Prince, went to the Towne of Sterling to meete the King, seeing a little without the Gate of the Towne a Stack of Corne, in Proportion not unlike to a Topp wherewith he used to play, he said to some that were with him, 'Loe there is a goodly Topp;' whereupon one of them saying, 'Why doe you not play with it then?' he answered, 'Set you it up for me, and I will play with it.'"

"Was not that a smart retort of the young prince?" said Mr. Goodenough. "It must have confounded the courtier who asked so silly a question."

"Tom, can you set up your top, so that it shall stand steadily on its point?" asked Mr. Seymour.

"I have often tried to do so," answered Tom, "but I could never succeed: the line of direction would never keep within so narrow a base."

"Yet, when the top is spinning, it steadily maintains the upright position. How is it that the rotatory motion occasions such a difference?"

"Is it not owing to the centrifugal force?" asked Tom.

"It is certainly not owing to the centrifugal force, although many people vaguely entertain the idea that that supposititious force will account for it. And I am not sure but that the elementary books are sometimes to blame for giving currency to loose notions of this kind. If we imagine the top to be spinning, so that the axis of rotation coincides with the axis of figure, the whole substance of the body may be conceived as made of rings

rotating about the common axis, and each ring, being uniform all round, may be supposed to be constituted of a series of particles similar among themselves. As these particles all revolve with a common velocity, and at the same distance from the axis of revolution, each one will have exactly the same tendency to recede from the axis. Hence, the axis being pulled equally all ways at once, those pulls will balance each other, and no pressure whatever will be produced on the axis."

"I see that the centrifugal forces can have nothing to do with it," said Tom, "since they certainly must balance each other all round."

Mr. Seymour now asked Tom to spin John's large humming-top. Tom, by a vigorous pull at the string, gave the toy so rapid an initial velocity, that it maintained its motion for a period which the younger boy regarded with no little admiration.

"The energy of motion which I impart to the top is used up in overcoming the friction of the point of the top on the floor, is it not, papa?" said Tom.

"Certainly that is one portion of the work which absorbs the moving energy; but the resistance due to the air is very considerable, although you might suppose the contrary, as there is no motion of translation. Tops, however, will spin in a space deprived of air for a far longer period than when they are surrounded by the atmosphere. But now spin the top again."

The toy then happened to begin its gyrations in an oblique position, out of which it gradually rose, the axis visibly changing its place by a slow circular movement, the circles becoming smaller and smaller, or, to speak more correctly, the upper extremity of the top's axis described a spiral curve, until it came at length to be vertically over the point on which the top was turning. The toy now continued to rotate so steadily that it scarcely appeared to move at all.

"It is sleeping, as we call it," said Tom.

"But have you remarked, Tom," said Mr. Seymour, "that, whereas, when the top began to spin, its centre of gravity was not over the point on which it was rotating, it is now exactly over it? Thus we have had a body, whose line of direction does not fall within its base, supported against the operation of gravity, and not only supported, but actually raised up; for I suppose you are aware that the centre of gravity of the top is higher when the top is in an upright position than when it is in

an oblique one? Now, what was the force which effected this change?"

"It could not have been centrifugal force, as you have already proved that that cannot produce any pull or pressure on the axis of the top."

"Then it must have been the resistance of the air," said Louisa.

"No; it was not the resistance of the air, for the same effect takes place in a vacuum. I will attempt to give an explanation by showing you how the operation of the laws of motion may produce this effect. I do not expect that you will be able to follow my explanation at once, simple as the phenomenon itself

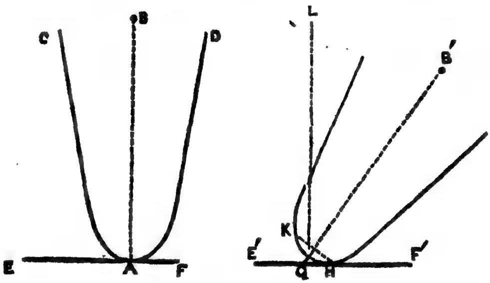


Fig. 79.

appears. In the first place, let us consider the effect produced by the conical shape of the peg upon which the top turns; but perhaps you have not all noticed that the top is terminated below in a somewhat *blunt* point; for it is found that a top with a fine sharply-pointed peg will not spin at all."

"I had a top which would not spin," said Tom, "until I had ground down its sharp point to a blunt one. But when I replaced the point by a flat surface, the top would not spin properly. The proper kind of shape I soon found to be a tapering one, with the extreme end rounded off."

"Now," said Mr. Seymour, "I will try to show you the reason of that. I shall first make a drawing representing the peg of the top on a very large scale (Fig. 79). Let C A D be the shape of the peg, A B the axis of rotation, which is here vertical. The peg touches the ground E F at the point A, and that being the

extremity of the axis of rotation, the top will continue to spin without a tendency to change, and it meets with less resistance than in any other position. But when the top leans over, it is no longer the point A which comes in contact with the ground, but some other point, H, about which the top is not rotating, or rather there must be a series of such points brought successively to the lowest position, H, by the continued rotation of the top about the axis G B′. And these points will plainly be a circle, which is shown edgeways in my drawing by the line H K, and which has its centre in the axis G B′. But as this rotating circle encounters resistance by the friction against the ground, its tendency will, of course, be to *roll* on the ground just as your marbles roll. This rolling motion of the circle H K would be precisely the same as if it formed the base of a cone, of which G, the point where G B′ meets the ground, is the centre. Now, before I proceed, you must become quite convinced that this rolling on the circle H K must take place, and that its effect would be to carry the axis G B′ round the point G, so that every point in G B′ would describe a circle, having its centre in the vertical G L."

"Then," cried Tom, "the whole top must be carried round G L as an axis; and this is, in fact, just what one sees, for the axis of the top moves slowly round as it is going to sleep. But pray go on."

"But you are overlooking this important circumstance, that if the cone H G K rolled on the ground, the revolution of the axis of rotation about the vertical G L would be as rapid as the revolution of the top itself, while, in truth, this turning round of the axis takes place so slowly as to be easily followed by the eye."

"I did not think of that: there must be something to check the motion: the friction, I suppose."

"The friction is precisely the cause of the rolling motion round G, or rather the sliding friction would be abolished when the cone rolled freely; that is, when it rolled as rapidly as the top spins. But as the top makes, perhaps, scores of revolutions while it is rolling once round on the cone G H K, the circle of points K H must be rubbed against the ground, and this sliding friction has sometimes been absurdly credited with the ability to raise the axis of the top to the vertical position by the reaction of the ground. I hope you do not suppose that the friction

of two surfaces, sliding against each other, produces a resultant force perpendicular to the surfaces?"

"I do not quite understand," said Tom.

"If I place this coin flat upon the table, and make it slide over the surface, you do not suppose that the friction tends to raise the coin up?"

"Certainly not," cried Tom; "the friction only opposes a resistance to your sliding the coin along the table."

"Well, then, if the axis of rotation G B′ be carried round the vertical G L by the rolling action, it follows that the planes in which all the parts of the top rotate must be constantly changing."

It required a few minutes' reflection to enable Tom to realize this last statement, but he soon grasped its meaning and perceived its truth.

"Now," said Mr. Seymour, "we have already learnt that the direction of a motion of translation cannot be changed from the straight line without the application of some force, and I shall presently let you feel that a body revolving about a centre cannot have the plane of its rotation changed without the application of some force. This is a consequence of the first law of motion, and that law, applied to the case we are considering, would show that the tendency of the particles of the top to preserve their planes of rotation reacts upon the axis, when the latter is shifted by the rolling motion; and one effect of the reaction is a force directed towards the vertical G L. You are not yet able to follow a geometrical explanation of these actions and reactions; but I hope that you will prosecute your mathematical studies with vigour, so that you may soon be able to understand the mode of investigating such questions. But I have the means of making you practically acquainted with the fact that a change in the plane of rotation of a revolving body can take place only by the application of some force; and you will then learn how it happens that the top's axis of rotation is only slowly carried round by the effort of the peg to roll on the little circle K H."

Mr. Seymour then produced one of those wonderful toys which are sold so cheaply at all toy-shops under the absurd name of Chinese tops. This toy is essentially a scientific invention, being, in fact, nothing more than an inexpensive form of the apparatus called the *gyroscope;* and, indeed, the toy which costs a shilling or less, as effectually illustrates some of the curious

results of the laws of motion in a rotating body, as the more elaborate forms of the gyroscope which the instrument-makers sell at a cost several hundredfold greater. The toy consists of a little fly-wheel with a massive leaden rim, A (Fig. 80), mounted on an axle, B, forming the diameter of a brass ring, C, in which the pointed extremities of the axle revolve freely in proper

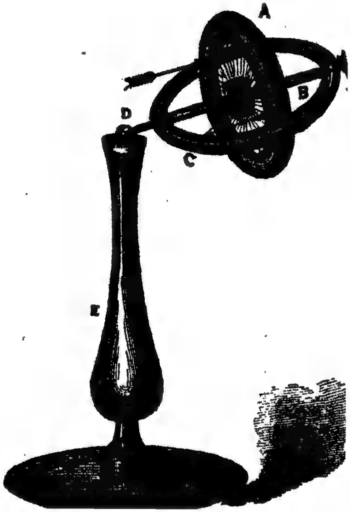


Fig. 80.

bearings. One of these is made adjustable by being hollowed out of the end of a short screw which, passing through the ring, terminates in the little knob, D. A very rapid rotation is given to the wheel by coiling a cord round the axle, and unwinding it precisely as in a spinning or humming-top. The first experiment Mr. Seymour showed with this interesting apparatus consisted simply in Tom holding in his hand the brass ring, while the wheel was in rapid rotation. He at once observed a peculiar resistance to his moving the apparatus, the peculiarity being that not only did the toy oppose the movement like a weight, but that, when moved, it showed a tendency to a lateral or twisting motion. This simple trial perfectly convinced Tom of the truth of his

father's statement about the change in the plane of rotation requiring the application of a force, and offering a resistance which constitutes the reaction to the force applied.

But great was the wonderment of all when Mr. Seymour, after announcing that he was about to show them a seeming contradiction to the law by which the unsupported centre of gravity must fall, set the toy in operation in the usual manner, for this effect had not before been witnessed by any of our juvenile friends. This was done by setting the wheel in extremely rapid movement, and then placing the knob D in a little hollow at the top of an upright stand (E), leaving the apparatus entirely unsupported, as shown in the figure. It must be understood that D is fixed in the ring, and does not revolve. When the gyroscope is left to itself, the brass ring turns slowly round about D on a centre in a horizontal direction, the ring not rotating, but passing several times round and round the stand nearly at the same angle with it.

"What a very extraordinary thing!" cried Tom, who had now acquired sufficient knowledge of the laws of nature to see that the phenomenon was strange and paradoxical: "the centre of gravity is utterly unsupported, and yet the top does not fall; the ring has no external force acting upon it, and yet it turns round!"

"But you know that there must be a force acting against gravity in this case; but if you will look attentively you will see that gravity is producing its usual effect of bringing the body down, only it does it slowly."

"Yes," said Tom; "I observe that the outer extremity of the axis is continually getting lower, and that instead of describing a closed circle about the stand, it is really descending in a curve, like that of a screw."

"You are quite right, my boy; and what you have observed with regard to the outer extremity of the axis is true also of the centre of gravity at its middle point: that also is descending, but in the kind of curved inclined plane which you have properly described as the curve of a screw."

"But what can be the force that prevents this heavy mass of metal from immediately falling down?" asked Tom.

"The force which you have just now felt, when you held the instrument in your hand—namely, the tendency of the rotating particles to continue in a fixed plane; and the reaction arising

from this tendency (which itself is an obvious case of the first law of motion) is so great that gravity can only impress upon the rotating body a very small vertical acceleration, at least so long as the requisite velocity of rotation is maintained."

"But what can be the cause of the horizontal motion?" eagerly inquired Tom.

"I should like you to try a little experiment," said Mr. Seymour. "Spin the top again, and note the direction in which the wheel revolves, and note also the direction of the slow movement. Then try again with the wheel spinning in the other direction, and I venture to predict that you will find the direction of the slow movement also reversed."

Tom proceeded at once to carry out these experiments, and they confirmed Mr. Seymour's statement.

"I observe," said Tom, "that in the horizontal movement the ascending side of the wheel goes first."

"The movement is then in the reverse direction to that which the wheel would have by rolling over the ground, for in that case the descending part of a wheel goes first. But let me try to explain to you the way in which the horizontal movement of our gyroscope may be conceived to arise. I draw the line D B (Fig. 81) to represent the axis of rotation, the thick line A representing the plane of rotation of a series of particles. The force of gravity, as you have seen, does bring down the axis; and confining your attention to the particles which are, let us suppose, rising up about E, you will observe that a lowering of the axis must cause the rising particles to be moving in the direction E G instead of E F—that is, they must have been pushed farther from D; and then their reaction operates in the direction of the arrow G F (Fig. 81). The opposition to the downward movement presented by the descending particles at the opposite side of the wheel has similarly a resultant operating in the direction shown by the arrow above D, Fig. 80. You will, no doubt, admit that if the wheel be pulled in the directions of the arrows B C and D A (Fig. 80) with equal forces, there will be impressed on the ring a movement of rotation about D, in the direction indicated by the arrow near the end of the axle B."

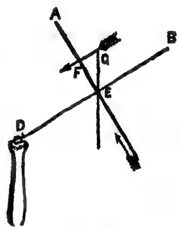


Fig. 81.

"I think I understand it," said Tom; "but I cannot be certain until I have leisurely studied your diagram, and compared it with the gyroscope itself."

"I do not expect," replied Mr. Seymour, "that you should at once understand a subject which certainly presents difficulties. But probably some reflection will show you that you have now a clue to the cause of the movements, for which at first no cause would be discerned."

"I have often wondered, since I began to think of the centre of gravity and the line of direction, how it is that a hoop, when trundled along, keeps upright, in spite of its narrow base. But after the experiments by which we have learnt the force necessary to turn aside the plane of rotation, I think the upright position of the rolling hoop must be maintained by the rotatory motion."

"There can be no doubt at all about that," replied Mr. Seymour, "for you would find it quite impossible to *slide* your hoop along in an upright position, even though you tried it on smooth ice."

"And I could never make out why, when a hoop is moving slowly, it does not at once fall flat on its side when its velocity is insufficient to maintain its balance; but as soon as it begins to lean over on one side, it also begins to move round in a circle. Sometimes it will go round and round, and it always rolls in a peculiar manner before it finally settles on the ground."

"The cause of the circular path taken by the hoop when it begins to fall by the action of gravity is, I am of opinion, of just the same nature as that which produces the slow rotation of the gyroscope. I believe that when you have thoroughly mastered the explanation I have given you of the gyroscope, if you will apply the same principle to the motions of the hoop, you will find a satisfactory solution of some of the difficulties which have occupied your mind. The motions of a coin rolled on the table are also very curious, and the rolling or vibrating movements before the coin finally settles offer many interesting problems; but I believe that these could all be solved by the adequate application of those principles with which you are now acquainted."

Thus did Mr. Seymour, taking the subjects of his lessons from the every-day pastimes of the children, lead them to recognize the natural laws in operation around them. Nor did this method

fail in awakening in their minds a new and abiding interest in those phenomena, which so constantly present themselves, that by the unreflecting they are regarded as too common to excite interest, and too simple to merit inquiry. The young people of Overton Lodge were now beginning to perceive that every object was capable of yielding some instruction and of illustrating some principle. Though Miss Villiers was usually present at these lessons, she generally allowed the scientific conversation to be carried on entirely by Mr. Seymour and her young friends. She was herself, however, tolerably well informed on many of the subjects which came under discussion; and though she felt much interest in Mr. Seymour's explanations, she did not interfere by any remarks of her own with the course of philosophical development of his children's ideas which Mr. Seymour was pursuing. Not but that by giving utterance to some pertinent, or perhaps witty, observation, she occasionally became an interlocutor in these dialogues; and indeed, she often debated with the vicar the question of the superiority which he was ever disposed to claim for the ancients over the moderns.

CHAPTER XVIII.

> My eyes are dim with childish tears,
>   My heart is idly stirred,
> For the same sound is in my ears
>   Which in those days I heard.

THE account of the scientific pastimes and philosophical conversations of which Overton Lodge was the scene, has so largely engrossed the preceding pages, that there have been passed over without notice some incidents which contributed to bring about remarkable and important events in the personal history of more than one of our characters. These unrecorded incidents are, however, of minor consequence, and a few words of explanation may suffice to describe circumstances that will serve to continue the thread of our narrative. Into this thread, had our plan permitted, might have been spun the recital of many conversations illustrative of the charming qualities of the young lady who, by every prescriptive right and usage of tale-telling, is still entitled to be called our heroine. Like "Orient

pearls at random strung," instances might have embellished these pages of her unaffected sweetness of disposition; of her refined accomplishments; of her intellectual culture; of her lively sallies of harmless mirth and inoffensive wit. That the details of Laura's sojourn at Overton Lodge must pass unchronicled, we regret the more as there are no exciting events to relate—no "moving accidents by flood and field," no "hair-breadth scapes"—by which a reader seeking only for amusement might be entertained. Nay, we may reasonably fear that our readers—especially those whose sex gives them the privilege of impatience, if any such should have followed the course of these chapters—must, by this time, be losing all interest in the fate of the personages in this halting story.

The increasing cordiality in the intercourse between Major Barker and Mr. Goodenough was marked by the lessened reserve with which the former mentioned his own circumstances. He spoke freely of the events of his early career; alluded to the isolation of his position, in which the declining years of his life appeared destined to lack the comforts of domestic ties and family relationships; and he referred in touching terms to the existence of his sister's son. In the most delicate and sympathetic manner the vicar hinted that there might be nothing to prevent his friend from seeking out this nephew. The major did not reply at the time, but it was becoming evident that the haughtiness of spirit which had so long sustained his determination against the promptings of an otherwise kind and naturally affectionate disposition, was beginning to yield. Nay, the vicar pictured to himself the happiness which might ensue should the major's nephew prove worthy of his relative's affection and be adopted by him; he saw in his mind's eye, his gallant friend's age passing in more contented days; he conceived that in his nephew's affection the old officer might find a solace for his disappointments, and might feel that by adopting him he would be atoning for the conduct towards his sister, which he perhaps now saw to have been an error and a fault. "Thus," thought the good vicar, "when the only possible reparation shall have been made for the ungenerous deeds and the harsh conduct,

"'Meek repentance, wafting wallflower scents
From out the crumbling ruins of fallen pride,'

may yet sweeten the memory of the past."

Shortly before the period at which we have now arrived, Mr. Seymour had made the major's acquaintance; calls had been interchanged between the Cottage and the Lodge, and the major was now invited to dine with the Seymours. The dinner party was a very cheerful one, and the major was perhaps in better spirits than he had been at any time since his arrival at Overton. The conversation was so general and ranged over so large a variety of topics, that we have no intention of recording any part of it. We will, however, if the reader pleases, join the company in the drawing-room, where Miss Villiers has just been asked to sing.

Laura was an excellent musician: she possessed a voice of much power, richness, and flexibility, and her singing was always distinguished by taste and feeling. She never selected a piece the words of which were inane or silly, for she held that music should ever be "married to immortal verse." Finding that this union was by no means the rule in the present day, Laura had acquired some considerable ability in herself adapting words to melodies, and in finding melodies for words. Especially happy was she with short lyrics and ballads from German sources, which, with a little occasional aid from her father, she would translate or adapt for her purpose in a metrical form. In all her pieces her full appreciation of the poet's intentions, and her power of giving them musical expression, made her execution seem something more than mere singing; it appeared to amount to a kind of impassioned declamation, in which harmony was blended with pathos, and melody was made instinct with meaning. This power of giving simultaneous expression to the poetry and the music caused our heroine's singing to produce deeper and more pleasurable impressions than even a much finer voice labouring through the *bravura* brilliancies of intricate airs.

There was nothing, however, in Laura's vocal talents, or in the words of the ballad which she readily and with an easy grace consented to sing, that would explain the strange effect which her performance produced on Major Barker. He was observed to listen with an intentness, and to gaze on the fair performer with an earnestness, which were quite remarkable. Mrs. Seymour noticed also that after this he ceased to join in the conversation with the same liveliness as before, and that he spoke with the kind of effort which is perceptible in the discourse of a person whose mind is pre-occupied by its own thought. She

divined that in point of fact something in Laura's performance must have touched a chord in the major's bosom, and we may at once inform our readers that in this observation she was correct. The major had, indeed, heard in the simple and pathetic ballad a voice which the others could not hear—a voice which seemed to call out of the long-vanished past. The melody, too, was one he had heard before—long before; and never since —— But what has greater power of reviving old associations than a strain of music?

The next morning was bright and sunny, and Mr. Seymour met the children in that part of the grounds which was peculiarly their own, and was appropriately called the play-ground.

"Tom," said his father, "bring me a saucer with some hot water, a piece of soap, and a tobacco-pipe. I have promised to teach John the art of blowing soap-bubbles."

Tom immediately proceeded to execute his commission, and shortly returned, bringing with him all the necessary materials for bubble blowing. John, under the direction of his brother, made the lather; and Mr. Seymour, turning towards the elder children, asked them whether they understood the philosophy of the operation they had just witnessed. They were, however, unable to return a satisfactory answer, and their father, therefore, proceeded as follows:

"Most liquids, by agitation, exhibit the appearance of froth, in consequence of small bubbles of air being forced into them by the operation. If, however, the liquid be viscid and tenacious, like soap and water, the air is imprisoned, as it were, in the mass, producing the appearance which is commonly called *lather*."

Louisa here inquired whether the air did not escape with more or less readiness, according to the degree of resistance it met with in the liquid.

"It is on that very account," Mr. Seymour proceeded, "that spirit, after it has been shaken, so soon regains its transparency; for, in consequence of the superior lightness of that fluid, and the little cohesion which subsists between its particles, the air makes a rapid escape. In like manner we may account for the spongy appearance which gives such superiority to our bread: in that case, the air disengaged during the fermentation of the dough cannot escape through so viscid a mass; it therefore remains, and thus produces the eyes or bubbles which you may always observe in every well-baked loaf."

"See, papa!" exclaimed Tom, "the bubbles which John has blown in the lather are not round, but angular figures—they are bounded by surfaces which appear to be hexagons."

"They are certainly hexagonal," replied Mr. Seymour; "and the form arises from the pressure of the bubbles upon each other. The same appearance is to be seen in the pith of vegetables when examined by the microscope, and is the result of the general reaction of the solid parts, similar to that which takes place in the honeycomb."

"I thought, papa," said Louisa, "that the form of the cells in the honeycomb was to be ascribed to the skill of the bee."

"That is a very general opinion, but it is not correct; it is now acknowledged to be the effect of the mechanical laws which influence the pressure of cylinders composed of soft materials. The nests of solitary bees are uniformly circular, and the cells of the pith of wood are only hexagonal in the central parts; towards the extremity, where there is but little pressure, they are circular. But let us proceed to blow some bubbles: plunge the bowl of the tobacco-pipe into the lather."

Tom obeyed his father's directions, and blowing through the stem, produced a bubble.

"See! see!" cried Louisa, "what a beautiful bubble!—but there is a quantity of soap hanging to its under part."

"I will take it off with my finger," said Mr. Seymour.

"There it goes!" exclaimed Tom.

"What beautiful colours it displays!—as bright and various as those of the rainbow," observed Louisa.

"It has burst!" cried Fanny and Rosa, in a breath.

"Ah, my dear children," murmured the vicar, with an air of pensive gravity, "'*Tenues secessit in auras,*' as the poet has it. Even thus is it with all the full-blown bubbles of our fancy, raised by the breath of hope: the moment they appear most vivid and promising to our imagination, they vanish 'into air—into thin air,' like the gaudy and unsubstantial soap-bubble you have just witnessed. But proceed to blow another; for you must seek, from a succession of bubbles, the prolongation of an amusement which no single one can afford you."

"I wish," said Tom, "that I could discover some method of preventing their bursting so soon, for there is scarcely time to examine them before they vanish. What can be the cause of their short duration?"

"Consider, my dear boy," said Mr. Seymour, "the frailty of their structure, and I think that the precarious tenure of their existence will cease to astonish you; indeed, the wonder is that they should endure so long. The film of which they consist is inconceivably thin, so that the slightest impulse is apt to rupture them; besides which, there must be a considerable evaporation going on from their surfaces."

"And could not the evaporation be prevented?" asked Tom.

"With a view of retarding the evaporation," said Mr. Seymour, "it has been recommended to mix glycerine with the soap solution; and doubtless this addition presents great advantages, for bubbles blown with it will, it is said, last several hours. But the mixture must be prepared with careful attention to the proportions of the ingredients."

"Pray do, papa, tell us how to make this mixture," cried Tom.

"The instructions which have been given for its preparation," replied Mr. Seymour, "are to dissolve one part by weight of pure soap in 40 parts of distilled water, and filter the liquid. Then two parts, by measure, of pure glycerine are to be long agitated with one part of the soap solution, and the mixture afterwards left to itself for some days. It will then be found that the mixture has separated into two liquids: a clear one below, and a turbid one above. The lower liquid must be drawn off by a siphon and preserved for use. But I have preserved ordinary soap-bubbles for a considerable time by blowing them through a tube in a large flask of clear glass, which was then immediately closed. As we have not such a flask at hand, you may try the experiment with a water-bottle of plain blown glass;—or, stay, we may perhaps succeed in showing that increased permanence of the bubbles is secured by retarding the evaporation by merely getting one of our bubbles to rest upon a flat surface, and then covering it with an inverted glass. Do you, Tom, obtain a tumbler, and we will at once try this plan."

Fig. 82.

When Tom returned with the glass, it was found possible, after a few trials, to cover a bubble with the glass, as shown in the annexed cut (Fig. 82), and the party were much pleased to have the opportunity of leisurely viewing the gorgeous colours. But while the attempts at securing a bubble under the glass

were in progress, little John was pursuing the amusement in his own way, namely, by blowing the bubbles with the tobacco-pipe in the ordinary manner, and detaching them, so that they floated away in the sunshine. The brilliancy of the tints, which indeed excited the admiration of all present, so delighted the little fellow, that he shouted again, and, elated with his success in producing these beautiful but evanescent objects, he declared that such splendid bubbles had never before been seen.

"These colours are like the tints of the prismatic spectrum," said Louisa; "but I cannot understand how they are produced by a mere film of soapy water."

"The colours are, indeed, like those produced by the prism, the result of the decomposition, if I may so term it, of ordinary sunlight; but the explanation of the way in which, according to the theory of light, thin transparent films are able to produce these effects, would be beyond your ability to follow in the present state of your knowledge. But I may show you some instances of the same effects, where the thin films are produced by other means; and I think that with these demonstrations of the power of such films to separate the coloured rays which make up ordinary light, you must for the present be content, and leave the investigation of the theory of the phenomenon until you are able to grasp ideas of a much more abstract character than any I have yet brought before you."

"Till that period arrives, then," observed Mr. Goodenough, "we must content ourselves with the facts, and our motto must be '*Causa latet, vis est notissima.*' However, let us, by all means, see other instances of the beautiful effects of colour which these thin films are capable of producing."

Mr. Seymour accordingly directed Tom to bring a flat piece of glass, which happened to be available, and well adapted for the experiment. It was simply a flat plate of ordinary transparent glass, which formed the cover of a circular case. When the surface of the glass had been cleaned, it was touched with a piece of soap; the soap was then spread over the surface with a moist cloth, and finally *almost entirely* wiped off the surface, which then appeared clear and transparent. Tom was now directed to breathe upon the glass through a tube in the manner shown in the annexed drawing (Fig. 83). Immediately a zone of the most beautiful tints started into existence on the surface of the glass, and were displayed in their full brilliancy when a

black object was placed behind the plate—in fact, Tom afterwards painted the back surface of the glass plate with black varnish, and this had the effect of bringing out the colours to

Fig. 83.

the greatest advantage. The tints produced by breathing on the soaped glass were, however, even less permanent than the hues of the soap-bubble, for they were occasioned by the deposition of an extremely thin film of moisture derived from the breath, and as this moisture, of course, rapidly evaporated, the colours were no sooner formed than they began to vanish. But it was noticed by everybody that the tints changed in rapid succession as the evaporation proceeded; and from this fact it was not difficult to infer that the *thickness* of the film influenced the kind of rays sent to the eye.

The formation of films thin enough to show the colours was exhibited to the children in several other ways. For instance, a drop of oil spread out upon the surface of water provided a more permanent display of the tints; and Mr. Seymour brought out from his cabinet of minerals, specimens of Iceland spar, which, although perfectly transparent crystals, showed, in certain lights, in those parts where the crystal was cleft by the excessively thin fissures so common in this and in other minerals, the same kind of colours as the soap-bubbles.

"Interesting as are the optics of the soap-bubble," said Mr. Seymour, "we must leave that branch of scientific illustration

to be dealt with on some other occasion. I have at present something to bring forward about the *mechanics* of the bubble."

"Why, papa," exclaimed Louisa, "is it possible that there can be *forces* acting on so frail a thing as a soap-bubble? I am sure that it would give way to the very smallest strain of any kind. But look at the bubble Tom is blowing; it is of an oblong shape, like an egg. There it goes! But, I declare, it is now perfectly round! What can be the reason of its changing its figure?"

"The bubble was elongated by the stream of air which issued from the bowl of the pipe," answered Mr. Seymour, "and the cause of its spherical form when detached you will presently learn. But, Tom, what are you musing about?" He had observed that the boy's attention was fixed upon the bowl of the tobacco-pipe. "I am sure, from your countenance, that something is puzzling you."

"You are right, papa: I was just then thinking how it can possibly happen that the bubble should not have a hole in its upper part; for, while I am blowing it up, there must, of course, be a communication between my mouth and its interior, or else how could the air pass into it?"

"True," said his father; "but when thrown off the bowl of the pipe, the breach is immediately united by reason of a very remarkable property of the film, which often passes unnoticed. The fact is, that the film behaves as if it were an elastic skin blown out like the thin India-rubber 'balloons.' The film has a tendency everywhere to contract on itself, and it does in fact draw itself together with a certain force, the existence of which I will try to demonstrate. When you, Tom, have blown a bubble of a moderate size, remove the pipe from your lips and keep it still, without detaching the bubble, which you must carefully observe."

When this was done, every one noticed that the bubbles were continually shrinking in their dimensions by the contraction of the film, and that their contractile force sufficed to expel from the open end of the pipe, the air which had been blown into them. Mr. Seymour explained that the force with which films of various liquids tend to contract had been measured. For example, a film of pure water 1 inch broad is stretched, as it were, with a force equal to the weight of nearly 3 grains. Two other beautiful experiments with the soap films were shown to

illustrate the tendency of the film to contract uniformly upon itself. A ring about 2 inches diameter was formed by twisting a piece of brass wire so as to leave a projecting handle. An extremely fine thread was attached to two points of the ring, and when the ring was dipped into the soap solution, a film was formed across it, in which the loose thread floated indifferently as at A, Fig. 84. But when Mr. Seymour took a little roll of blotting-paper and touched the film within the thread, the film there immediately broke, and the tension of the remaining part drew the thread out into a beautiful regular curve as shown at B, Fig. 84. The experiment was varied by attaching only one end of the thread to the ring, and forming the other into a loop which floated indifferently in the film until the latter was removed from the inside of the loop, when the tension instantly caused the loop to assume the form of a perfect circle, as represented at C, Fig. 84. Mr. Seymour went on to explain that just as they had seen the tension of the flat film drawing the loop into a circle, so in the soap-bubble the contractile force causes the film to assume the form in which the surface is the smallest possible, and that form is the spherical one.

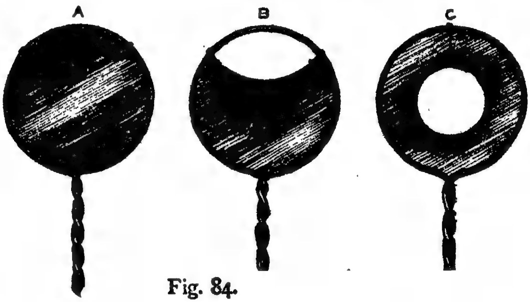


Fig. 84.

"But it has been found," Mr. Seymour continued, "that the surfaces of all liquids exhibit the same kind of tension, or effort to contract, which we have observed in these soap films. This is the reason why the drops of dew on the cabbage-leaves are spherical. It is not difficult to prove that at the surface of the liquid, the water in this tumbler is in a condition different from that in which it exists within the mass. You know, for instance, that iron sinks in water, yet if I take very small bright needles, which are not readily wetted by water, I shall be able by carefully placing them on the surface of the liquid to cause them to swim thereon. If Louisa will bring me from her work-box a

packet of fine small needles, I will show this curious experiment of floating iron."

Mr. Seymour succeeded without difficulty in floating a dozen of the needles on the surface of clean water in a basin. He explained that the water behaved as if it had a thin skin stretched over its exposed surface, and this would support any very small bodies which were not liable to be wetted by water, for in that case they would destroy the continuity of the superficial film. He exhibited an illustration of the last statement—the very curious movements which are observed when a minute fragment of camphor is placed on the surface of hot water. The children were much amused to observe the apparently anxious movements of the little piece of camphor. It rushed now in this direction, now in that—twisting and pirouetting about its axis in the most extraordinary way. These effects were explained by the superficial currents which radiated in all directions from the camphor, in consequence of its producing by its solution a diminution of the tension in the external film of the liquid. And as the solution does not take place regularly all round the camphor, the more powerful currents prevail, and carry the particle about.

Mr. Seymour informed the children that the ascent of liquids in narrow tubes was believed, with good reason, to be also an effect of the tension in the free surfaces of the liquid. He showed that the contractile force of the surface film would cause two bodies wetted with the liquid to approach each other when they were free to move. Thus two pieces of cork, placed in a cup of water, moved rapidly towards each other, or towards the edge of the vessel, when they were brought within a short distance of each other. This phenomenon had by some careless authors been attributed to the attraction of gravitation. But that it was really due to the surface action of the liquid Mr. Seymour proved conclusively by taking two dry corks, and after oiling *one* of them, placing them in the water, when they were found to exhibit an apparent repulsion for each other.

CHAPTER XIX.

You wander through the philosophic world,
Where in bright train continual wonders rise.

"WE will now proceed," said Mr. Seymour, "to consider the action of those toys which operate by the weight and pressure of the atmosphere. Tom, fetch your leather sucker."

"John is, at this moment, amusing himself in the garden with the one which I brought with me from school," replied Tom.

"Then you shall construct another for yourself. Here are leather and string."

"This leather is too stiff; but I may, perhaps, make it answer the purpose by first soaking it."

After the boy had allowed the leather to remain in water for a short time, it became sufficiently pliable for his purpose; he then cut it into a circular shape, and passed a string through its centre. The juvenile party now hastened to the play-ground,

and after having there once again dipped his newly constructed sucker into the water, Tom placed it upon a stone, pressed down the leather with his foot, and succeeded in raising the stone in the manner depicted in the annexed cut (Fig. 85.)

Fig. 85.

"Well done, my boy. Now explain the reason of the leather's adhesion to the surface, and of its being thus capable of retaining its hold, notwithstanding the weight of the stone."

"In the first place," answered Tom, "the wet leather was closely pressed to the smooth surface of the stone, and as I pulled the string upwards a hollow was formed in the middle part of the leather; for the wetted margins of the leather were so closely pressed against the stone that the air could not get into the hollow, which, like any other place empty of air and of everything else, is called a *vacuum*."

"Very well," replied his father: "so far you are right; but you have not informed me in what manner a vacuum acts in preventing the stone from quitting the leather."

"It makes it adhere to it by some kind of *suction*, but I confess that I do not exactly understand the subject."

"Your idea of a vacuum being formed in the hollow part of the leather is perfectly correct; for, as you draw up the central part by the string, the hollow thus produced must necessarily be a vacuum, since the air cannot pass through the leather to supply it; in this state, therefore, the atmosphere presses upon the exterior of the leather, and, like any other weight, prevents its rising from the stone."

"I quite understand that the atmosphere can press down in this way, but that would not keep the stone up."

"I have yet to tell you that the pressure of the atmosphere differs entirely from the pressure exercised by a solid body, inasmuch as the atmospheric pressure is exerted in all directions at once."

Tom and Louisa were unable at once to comprehend the possibility of such a state of things. Mr. Seymour, after inform-

ing them that gases and liquids had the property in common of free movement of their particles among themselves, asked them to consider the condition of a particle, or very small portion, of the water contained within a vessel, and at rest.

"Let us picture to ourselves," said he, "a particle of water within the mass in yonder butt: it is motionless; but I think you must perceive that there is one force at least acting upon it—the pressure, namely, which results from the weight of the column of particles above it, and to which it serves as base. It is evident that this pressure must be balanced by an exactly equal one directed upwards."

"Of course it is," cried Tom: "there is the reaction of the next particle below it. But what I do not understand is how it can be pressed sideways without moving."

"You would not expect it to move if the lateral pressures were equal in every direction. But if I were, from any portion of the water, to remove the pressure in any assigned direction, the water would be immediately forced in that direction. For example, when I take away from a part of the water in the butt the reaction of the internal surface of the vessel, the lateral forces would manifest themselves by imparting motion to the water."

"But you could not prevent the reaction from taking place, as there can be no exception to the third——"

"Of course there can be no exception to the third law of motion, for the reaction would, in the case I suppose, take place between the moving and the propelling water; but the motion of particles of water next the internal surface of the vessel, when no longer resisted by its reaction, would at once show the direction of the impelling forces. Now, I need not tell you that if I bore a hole through the side of this vessel the water will be forced out, and I suppose you know that the greater the distance below the surface at which I made the hole in the butt, the greater the force with which the water would issue from it. This circumstance shows that the lateral pressure at any point arises from the weight of the column of water above the point. Now, the very same thing holds good in the case of the atmosphere, which exerts a pressure in every direction upon all bodies immersed in it—a pressure which is the result of the weight of the air itself."

Fanny and Louisa here expressed some surprise on hearing

of the weight of the atmosphere; the former observed that she did not feel any pressure from it. Their father explained the reason of their not being conscious of the weight, by informing them that their bodies contained air, which, by its resistance, counteracted the pressure from without, that had been ascertained by experiment to be equal to 15 pounds upon every square inch of surface, or as much as 40,000 pounds upon the body of a man of ordinary size.

Mr. Seymour here exhibited to the children a pleasing, because simple, illustration of the pressure of the atmosphere. He obtained a tall upright glass jar, like those in which confectioners display their wares, and ground the top edge of the jar perfectly level and even by carefully rubbing it on a smooth flat slab of stone which had been wetted with turpentine. This done, a little tallow was smeared on the ground edge of the vessel, so that a glass plate when placed upon the latter might fit perfectly air-tight. He then entirely filled the jar with water, and placed the flat piece of glass over the mouth of the jar, which he carefully inverted, and the spectators then saw the whole weight of water, perhaps 10 pounds or more, resting on the glass plate, which seemed to be supported on nothing, but which was really upheld by the upward pressure of the atmosphere. This pressure Mr. Seymour explained would be sufficiently powerful to maintain in the same way a much longer column of water; in fact, the height of the column of water, instead of being 1 foot, might be 30 feet, and yet the atmospheric pressure would be sufficiently powerful to counteract the weight of the liquid. He stated also that if the smallest opening were made in the top of the inverted vessel, the atmospheric pressure would reach the top of the liquid column, which, then being pressed down as much as it was pressed up, would of course fall by its own weight.

The same experiment of the inverted glass was repeated on a smaller scale by filling drinking-glasses with water, covering them with a piece of cardboard, and then turning them upside down without spilling the water. The experiment is a very simple and telling one, and John and the other little Seymours had no difficulty in performing it in the manner depicted in Fig. 86.

"Until your explanation," said Tom, "I really believed that the leather adhered to the stone by some kind of suction, just as the back of my hand adheres to my lips whenever I place it to my mouth, and draw in my breath."

Mr. Seymour here expressed a doubt whether his son was even yet a perfect master of the subject: he told him that there was no such operation in nature as *suction*—that it was merely a popular term to denote, in certain cases, the action of the pressure of the air when that pressure was not completely opposed by equal pressures.

Fig. 86.

"Your hand," said he, "seems to adhere to your mouth in consequence of your forming a partial vacuum within by forcibly drawing in your breath, and the resistance which is opposed to its removal arises entirely from the pressure of the atmosphere upon your hand. Many are the effects which may be explained upon a similar principle. I dare say you recollect the astonishment you expressed at the force with which the limpets attached themselves to the rocks."

"Oh, yes, papa," exclaimed Louisa, "I well remember, when we walked on the sea-shore, that on first touching the limpets they appeared loose and movable; but before I had time to remove them they fastened themselves as firmly as though they had been a part of the rock upon which they were fixed. How could that happen?"

Mr. Seymour replied that these creatures possessed the power of converting their bodies into suckers, and he informed them that many other animals were endowed with a similar faculty. He instanced the tentacles of the octopus, which are furnished with many such suckers, by means of which the animal is enabled to hold with wonderful tenacity to whatever it attaches itself.

"Have you never observed," he continued, "the security and ease with which flies can walk with their bodies downward upon a smooth wall, or a pane of glass, or along the ceiling?"

"To be sure," replied Tom; "but are not their legs provided with some sticky matter, which enables them to preserve themselves from falling?"

"That is a popular error, my boy. The fact is, that their feet

are provided with little flaps, or suckers, which they alternately exhaust and fill with air."

At this moment Tom's stone fell from the sucker. Louisa inquired how it could have happened.

"The circumstance is to be easily explained," said her father. "The atmosphere, by its pressure, ultimately forced its way through the edges of the sucker; its interior, therefore, became accessible to the atmospheric pressure, which, of course, balanced the same pressure exerted on the bottom of the stone and on the top of the sucker. These bodies being no longer pressed together, there is nothing to prevent the stone from falling to the ground."

"If the atmosphere exerts so great a pressure, and has so much weight," observed Louisa, "it is strange to me that it should not fall down on the earth."

Mr. Seymour replied, "that the air is distinguished by its elastic properties; for when pressure is applied to any portion of air, it yields to that pressure by condensing into a bulk smaller and smaller in exact proportion as the pressure is greater, and at the same time, as it is always ready to expand again as the pressure is removed, it constantly reacts against the pressure applied to it."

"But I suppose," said Tom, "that it gravitates, or is attracted by the earth. What, then, can be the reason, as Louisa says, that it does not fall, like any other body, to the ground?"

"And so it actually does," replied Mr. Seymour. "The lower stratum of the atmosphere rests upon the ground, but the strata above it do not fall, because they are supported by the particles beneath them, in the same manner as the water at the surface of a basin is supported by that at the bottom: the only difference is, that in one case the fluid is easily compressible, and in the other, almost incompressible. Water, moreover, on the removal of the compressing force, resumes its original dimensions; whereas air continues to expand more and more by the removal of pressure. It is the action of gravity on the atmosphere itself which retains it always in a state of compression."

"If, then, the force of gravity were diminished," observed Louisa, "the air would become much lighter, and I suppose that is the true reason of its being so much less dense in the upper regions; for I am quite sure that I have read an account of the air being so extremely light upon the top of a high mountain, as to affect the breath and occasion great uneasiness."

"I do not deny the fact, my dear, I only question your explanation of its cause. Can it not, think you, be accounted for upon some other principle than that of the diminished force of gravity?"

Louisa was unable to suggest any other probable reason.

"The fact, then," said her father, "is simply this: since the air is elastic, or capable of yielding to pressure, so, of course, the lower parts must be more dense, or in a greater state of compression, than those which are above them. In a pile of fleeces of wool, are not the lower fleeces pressed together by the weight of the superior ones, and do they not lie light and loose in proportion as they approach the uppermost fleece, which receives no external pressure, and is confined merely by the force of its own gravity?"

"Clearly," said Louisa.

"Well, then, we will suppose, for example, that the whole column of the atmosphere were divided into a hundred parts, and that each of these parts weighed an ounce, would not the earth, and all things on its surface, be, in such a case, pressed upon with the whole hundred ounces?"

"No one can deny that!" said Tom.

"The lowest stratum of air," continued Mr. Seymour, "would be pressed upon by the 99 ounces above it; the next by 98; and so on until we arrived at the ninety-ninth stratum from the bottom, which would, of course, be subjected to no more than one ounce of pressure, or to the weight of the last and highest stratum."

The children were perfectly satisfied with this simple explanation; and Tom inquired whether, for the same reason, the water at the bottom of the sea must not be very dense, and unlike that we are accustomed to observe on the surface. His father, however, corrected this notion by stating that water not being, like air, highly compressible, the water at the bottom of the sea would not suffer any material diminution in volume, although pressed by the enormous weight of the superincumbent water.

"Before we quit the subject of the air's elasticity," said Mr. Seymour, "we might consider the philosophy of the *pop-gun*, an amusement with which, I have no doubt, you are well acquainted."

"Indeed I am, papa; but do you allude to the quill, or to the wooden pop-gun?"

"The principle in both is the same. Tell me, therefore, the origin and nature of the force which enables you to shoot your pellet to so considerable a distance."

"It depends upon the action of the air," replied Tom.

"Undoubtedly; but your answer is too general. I wished you to state in precise terms the changes which the air undergoes upon this occasion. You first ram in your pellet to the farther end of the tube, do you not?"

"To be sure; and then I drive in a second pellet, and on forcing this forward, the first flies out with considerable force."

"Very well: now examine what takes place. On pushing forward your second pellet, you condense the air which is enclosed between the two, until its elastic force becomes so great as to overcome the friction of the first pellet; thus released, the air expands and imparts a rapid motion to the pellet. But I have now to present John with the modern improvement over the old-fashioned pop-gun."

Mr. Seymour gave the younger boy one of those elegant and wonderfully cheap French toys, in which the paper pellets of the original toy were replaced by a neat piston of india-rubber moving in a bright brass tube, into the mouth of which the small corks forming the projectiles were inserted. The metallic handle of the piston, shaped in the semblance of the stock and lock of a pistol, gave quite a warlike appearance to the toy. The vicar took occasion to remark that for his part he much preferred the primitive form of the toy, especially when it is home-made; for he was of opinion that the concentration of the thoughts and the employment of fingers in fashioning, however rudely, of a piece of elder-wood into a pop-gun, and the feeling of successful achievement when the juvenile fabricator gets his little machine to work, are in every way worth more to the boy himself than the gratification he might find in a whole bazaarful of ready-made toys.

"I have frequently heard of the air-gun," said Louisa: "I suppose it depends upon the very same principle as this little toy of Johnny's?"

"It does; and it affords an example of the surprising force which air is capable of exerting when much condensed; for, by means of this instrument, bullets may be propelled with a force very nearly equal to that of gunpowder."

"It is a curious fact," observed the vicar, "that although the

air-pump is a modern invention, yet the air-gun, which is so nearly allied to it in the construction of its valves and condensing syringe, should have existed long antecedent to it; for it is recorded that an air-gun was made for Henry IV. by Marin of Lisieux, in Normandy, as early as 1408; and another was preserved in the armoury at Schmetau, bearing the date of 1474."

"But the air-gun of the present day," said Mr. Seymour, "is very different from that which was formerly made, and which, like the pop-gun, discharged but one bullet, and that after a long and tedious process of condensation, while it is now made to discharge five or six without any visible variation of force, and will even act upon a dozen, but with less effect."

"I feel very curious to learn something more about this air-gun," said Tom.

"There is a reservoir for the condensed air," replied Mr. Seymour, "which is secured by a nicely constructed valve, and which is made to open by pulling the trigger of the gun, so that a portion only of the air is disengaged, which, rushing into the barrel, gives motion to the ball."

"But how is the condensed air introduced into the reservoir?" asked Tom.

"By means of a condensing syringe," replied his father; "but I will take an early opportunity of exhibiting the instrument in operation. But I see you are lost in thought about something."

"I was thinking," replied Tom, "whether the air-gun can be called a machine, for the energy of motion which is possessed by its bullet is certainly not due to the work done by the person who discharges the weapon by merely drawing the trigger."

"The air-gun, of course, comes under the law you are now alluding to; and the work is done upon the machine by the person who condenses the air, as you will soon discover when you come to use the syringe. The work so done is stored up, as it were, in the reservoir of condensed air, ready for employment in propelling the bullet, and in this way the energy expended on the condensing syringe might be preserved for an indefinite period. And you should know, although we cannot now discuss the subject, that when the air has been condensed into a vessel by the expenditure of a certain amount of work, that air cannot by any means leave the vessel, and be restored to its former condition, without its doing, in some way or other, precisely the amount of work which has been done upon it."

"This seems very extraordinary," said Tom, "and I confess I do not fully understand it. I certainly can imagine that work is done in compressing the air for an air-gun, for I feel the resistance which the air offers to compression in this toy gun of John's."

"Now, Tom," said his father, "fetch your squirt, for we have not yet finished our inquiry into the effects of the pressure of the air."

The squirt was produced; but it was out of repair, for when Tom attempted to fill it with water, the instrument entirely failed in the performance of its office.

"I see the defect," said Mr. Seymour, "which a little string will easily remedy."

A piece of string was instantly produced from that universal depot, the breeches-pocket of a schoolboy. Mr. Seymour said he should bind a portion of it around the end of the piston.

"What do you mean by the *piston?*" inquired Tom.

"The plug which moves up and down in the cylinder or tube; and, unless it fit so exactly as to prevent the admission of air, it is clear that the squirt cannot draw any water. It was for the purpose of making this part fit tightly that I wanted the string, and you will now perceive that the instrument is ready for use. Fetch me a vessel of water."

Tom soon produced the water, and on placing it on the ground, requested that he might be allowed to fill the squirt. This he accordingly effected without difficulty, and on pressing down the handle, he projected a stream of water to a considerable distance.

"I perceive," said Tom, "that the stream describes a curve like a projectile."

"To be sure; it is under the joint influence of the same forces, viz., that of projection and of gravity. But explain the operation of the squirt."

"As soon as I raised the piston an empty space was left in the lower part of the cylinder, which, I suppose, would have remained as a vacuum, had not the water rushed into it."

"And why did the water rush into it?"

Tom hesitated.

"Was it not, think you, owing to the pressure of the atmosphere upon the surface of the water? When you raised the piston, the air above it was also raised, and ultimately driven out by the force of the ascending piston; and since the air could

not find any entrance from below as long as the point was under the water, the interior of the squirt would necessarily have remained quite empty, that is, it would have been a vacuum, had it not been for the weight of the atmosphere, which, not having any counteracting pressure, drove the water into the tube, by the pressure it exerts on the surface of the liquid, and thus filled it. And, by pressing down the piston, you again expelled the water with considerable force."

"Your explanation," said Louisa, "is so clear and intelligible, that I feel quite confident I could now explain any machine that owes its action to the exhaustion of the air and the pressure of the atmosphere."

"If that be your belief," said Mr. Seymour, "I will not lose a moment in putting your knowledge to the test. Tom, do you run into the house, and fetch hither the kitchen bellows."

The bellows were produced, and Louisa, having been desired by her father to explain the manner in which they received and expelled the air, proceeded as follows: "Upon raising the upper from the under board, the interior space of the bellows is necessarily increased, and immediately supplied with an additional quantity of air, which is driven into it by the pressure of the atmosphere; when, by pressing down the upper board, it is again expelled through the iron tube or nozzle."

"To be sure," said Tom, "in the same manner that the water was expelled from my squirt when I pushed down the handle."

"So far you are quite correct," said Mr. Seymour; "but you have not yet told us the use of the hole in the under board, and which is covered, as you perceive, with a movable flap of leather: it is termed a valve."

"That," replied Tom, "is for the purpose of admitting the air when we raise up the board."

"Exactly so; and also to prevent the air from passing out again when you press it down. I wish to direct your attention particularly to this contrivance, because, simple as it may appear, its action will teach you the general nature of a valve. Without it the operation of filling the bellows with air would have been so tedious as to have destroyed the utility of the instrument; for the air could, in that case, have only found admission through the nozzle, and that again would have been attended with the additional disadvantage of drawing smoke and other matter into its cavity; when, however, you raise up the board, the air,

by its external pressure, opens the valve inwards, and thus finds an easy entrance for itself; and when you press the board downwards, the air, thus condensed, completely shuts the valve, and its return through that avenue being prevented, it rushes through the tube."

Mr. Seymour now proposed that they should proceed to consider the structure and operation of the pump.

"I suppose," said Louisa, "that the pump raises water in the same manner as the squirt."

"Exactly upon the same principle," replied her father; "but the machinery is a little more complicated, since its object is not to force the water out of the pump at the same end of the pipe at which we draw it in. We will, however, proceed to the stable-yard, and examine the pump; and do you, Tom, provide a piece of chalk, in order that I may make a sketch of some of its principal parts."

Thither our party immediately proceeded; and, as they walked along, Mr. Seymour desired the children to remember that the pressure of the atmosphere was equal to a weight of 15 pounds upon every square inch of surface; and that the moment the water arrived at such a height as to balance that pressure, it could ascend no higher; he added that the altitude at which such a balance took place was about 32 or 33 feet above the surface.

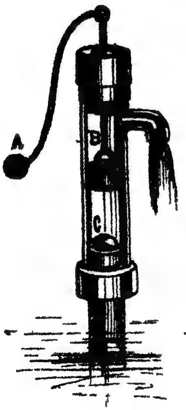


Fig. 87.

"If that be the case," said Louisa, "the pump, of course, can never raise water from any well of greater depth than that which you state."

"Not without some additional contrivance, which I shall afterwards explain to you," replied Mr. Seymour.

The party had, by this time, arrived at the pump; its door was opened, and as much of the apparatus exhibited as could be conveniently exposed. Mr. Seymour then chalked the annexed sketch (Fig. 87) upon the stable door.

"Is that a pump?" cried Tom. "I should never have guessed what you intended to represent, but for the spout and handle."

"It is not a perspective drawing, but partly a representation of the different parts as they would appear were it possible to cut the pump in half, from top to bottom, without disturbing any of its arrangements. A drawing of this kind, which is frequently used for the sake of explanation, is termed a *section*."

Mr. Seymour here took an apple, and having cut it in two, observed that the surfaces thus exposed presented *sections* of the fruit. This illustration was understood by all present, and Mr. Seymour continued, "I have here, then, a section of the common household pump. B C is the cylinder or barrel; B the air-tight piston which moves, or works within it, by means of the rod; C the valve, or little door, at the bottom of the barrel, covering the top of the feeding-pipe, and below it is the suction

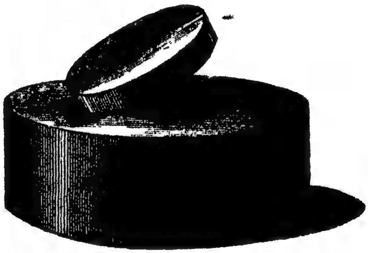


Fig. 88.

or feeding-pipe, descending into a well, or any other reservoir; there is a similar valve in the piston; both of these valves, opening upwards, admit the water to rise through them, but prevent its returning. As this part of the apparatus is no less ingenious than it is important, I will sketch the valve, or *clack*, as it is termed by the engineer, on a larger scale."

Mr. Seymour then sketched the annexed figure (Fig. 88), from which its construction was rendered perfectly intelligible to the children.

Mr. Seymour proceeded: "When the pump is in a state of inaction, the two valves are closed by their own weight; but, on drawing up the piston B from the bottom to the top of the barrel, the column of air, which rested upon it, is raised, and a vacuum is, or rather would be, if the valve C continued closed,

produced between the piston and the lower valve, C; the air beneath this valve, which is immediately over the surface of the water, consequently expands, and forces its way through the valve; the water then ascends into the pump, being, in fact, pushed up by the weight of the atmosphere pressing on the surface of the water in the well; for this pressure is transmitted in all directions throughout the liquid. A few strokes of the handle suffice to remove the air from the body of the pump, and fill it with water, which, having passed through both valves, runs out at the spout."

"I understand how water may be thus raised to the elevation of 32 feet, but I have yet to learn the manner in which it can be raised above that distance," said Louisa.

"It is undoubtedly true that, if the distance from the surface of the water in the well to the valve in the piston exceed 32 feet, water can never ascend above the piston-valve; but you will readily perceive that when once the water has passed the piston-valve, it is no longer the pressure of the air which causes it to ascend: after that it is raised by lifting it up, as you would raise it in a bucket, of which the piston formed the bottom; and water having been so raised, cannot, in consequence of the valve, which is kept closed by its pressure, fall back again. All that is necessary, therefore, is to keep the working barrel within the limits of atmospheric pressure; we have then only to fix a continued straight pipe to the top of the barrel, and to lengthen the piston-rod in the same proportion, and the water will continue to rise at each successive stroke of the pump, until at length it will flow over the top of the pipe, or through a spout inserted in any part of its side. The common pump may, therefore, be described as at once a *suction* and a *lifting pump*."

The party expressed themselves fully satisfied with these explanations, and Tom inquired who invented the machine.

"It is an instrument of great antiquity," said Mr. Goodenough; "but the principle of its action was not understood for ages after its invention. The ancients entertained a belief that 'nature abhorred a vacuum;' and they imagined that when the piston ascended, the water immediately rushed forward to prevent the occurrence of this much-dreaded vacuum."

"I am not quite clear," said Mr. Seymour, "that the phrase 'nature abhors a vacuum' was ever seriously advanced as an *explanation* of these facts. Might not this have been merely a

compendious expression for summarizing the facts? In the seventeenth century a pump was constructed at Florence, by which it was attempted to raise water from a well to a very considerable altitude; but it was found that no exertion of this machine could be made to raise it above 33 feet from its level. This unexpected embarrassment greatly puzzled the pump-maker, and Galileo was asked for an explanation of the circumstance. It is said that his reply was that Nature's abhorrence of a vacuum did not extend to greater distances than 33 feet, and that her efforts to fill the vacuum ceased at that point. Some have supposed that if Galileo really did make this answer, he did it sarcastically; but it is more probable that had he at the time been prepared with a more satisfactory solution, he would have advanced it, and that, failing this, he merely extended the hypothetical expression which had, up to that time, appeared consistent with the facts, by modifying it so as to include the new fact; thus, 'Nature abhors a vacuum—up to 33 feet.' It was Galileo's pupil, Torricelli, who first demonstrated that the pressure of the air on the water below is the cause of the liquid rising in the pump; and that as, when it has risen 32 feet, its pressure becomes equal to that of the atmosphere, it cannot rise any higher. The experiment by which Torricelli proved this was not only a conclusive one, but it provided the world with that highly useful instrument, the barometer; for the 'Torricellian tube,' as it was called, was really nothing more than a simple form of the barometer. This famous experiment consisted in filling with quicksilver—which is about thirteen-and-a-half times heavier than water—a strong glass tube about a yard long, and closed at one end. The open end of the tube was covered to prevent the escape of the quicksilver, until the tube had been inverted and its mouth brought below the surface of some more quicksilver in an open basin, when the end was left open, so that the liquid in the tube communicated freely with that in the basin. But here is a little sketch (Fig. 89) by which you will at once see what I mean. Well, what then happens with such an arrangement is

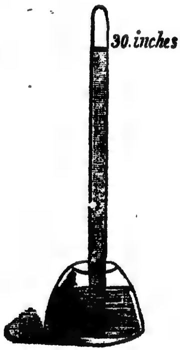


Fig. 89.

this: when the submerged end of the tube is opened, some of the quicksilver flows out, and unites with that in the basin, but only so much as suffices to bring the level of the quicksilver in the tube to about 30 inches *vertically* above that of the liquid in the basin. Thus the atmospheric pressure sustains a vertical column of mercury shorter than that of the column of water, in the same proportion as quicksilver is heavier than water. I hope before long to explain to you at large the uses of the barometer; it may be sufficient for the present that you observe that the height of the mercury in the tube will change when the pressure of the atmosphere changes. When that becomes greater, more mercury is forced up into the tube; when that is lessened, it is able to counteract the weight of only a shorter column of mercury, and consequently the height of the column in the tube is diminished by some of the liquid leaving the tube to enter the basin."

"But I cannot understand," said Louisa, "how the pressure of the mercury can balance the pressure of the atmosphere; for the former is exerted only over the narrow width of the tube, while the atmosphere presses upon the greatly more extended surface of the liquid in the vessel."

"It is a property of fluids," replied Mr. Seymour, "that a pressure applied to any part is transmitted throughout the mass, so that, on *equal areas* at every part, the same pressure is produced. Thus the small quantity of water in the spout of a teapot balances the larger quantity within the vessel, and the two portions of the liquid have always the same level. But it is now time to conclude your lesson: to-morrow I hope we shall be able to enter upon the subject of the kite."

CHAPTER XX.

> Nor purpose gay,
> Amusement, dance, or song, he sternly scorns;
> For happiness and true philosophy
> Are of the social still and smiling kind.

THE children were summoned into the library, and informed by their father that he was at leisure to explain the philosophy of the kite; a subject with which Tom had repeatedly expressed some impatience to become acquainted.

"It is a beautiful day," exclaimed the boy, joyously; "and there is such a delightful breeze, that I should really call it a complete kite-day."

"Gently, my fine fellow," replied Mr. Seymour: "the bird must be fledged ere it can fly. We have not, as yet, any kite, for you know that the one you possess is shattered beyond the possibility of repair."

"True, papa; but could not Robert just step into the village

and buy one? I saw several kites in the shop of Peg Robson yesterday."

"I do not doubt it, my boy; but the kites which are to be found in the toy-shop are made to sell rather than to fly, and to raise the wind for the benefit of the vendor, rather than to be raised by it for the amusement of the purchaser: we must, therefore, construct one for ourselves; and see, I have accordingly prepared all the necessary materials for the purpose. I have here, as you perceive, a straight lath of deal, about three-quarters of an inch wide, and less than a quarter of an inch thick, and about four feet in length; this is quite ready for forming the back-bone of the kite: and now for the bow. The cooper has complied with my directions, and sent an unbent hoop as free as possible from knots: you observe that it is about the same length as the lath, but it will be necessary to pare it down a little at each end, in order to make it bend more readily to the required shape."

This having been accomplished, Mr. Seymour proceeded to form the framework of the kite in the following manner: He first ascertained the central point of the hoop by balancing it on his forefinger; he then, by means of string, attached the hoop at that point to the lath, about an inch and a half from its end, as shown at A (Fig. 90); he next cut a notch in each end of the hoop, or bow, C D, and having fixed the string in the notch C, he drew it through another, B, previously cut in the other end of the lath, and carried it to the opposite extremity of the bow, D. The skeleton now presented the usual form of the kite. The next point, therefore, was to ascertain whether the two sides of the bow were in equilibrium, and this he determined by balancing the lath on the finger, and observing whether it remained horizontal or dipped on one side. This adjustment having been accomplished, Mr. Seymour next continued the string from D across the skeleton to the opposite notch C, giving it in its way one turn round the lath at E; from C it was carried to A, and wound round the top of the lath, and then again fastened at D; from D it was extended to a point F, about midway down the lath, and having been there secured, was finally carried again to the notch C,

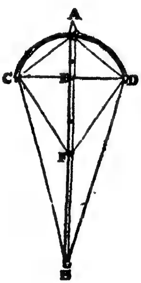


Fig. 90.

where it was tightly tied. The framework was now pronounced to be complete. We have been thus minute in our description of Mr. Seymour's operations, in order to afford our young readers some directions for properly constructing the essential part of a good kite.

The next part of the process was to cover the framework with paper. Mr. Seymour observed that the best kind which could be employed for this purpose was that known amongst stationers by the name of fan-paper, so called from its being manufactured for the use of the fan-maker: its merits, he said, depended upon the size of its sheets, as well as upon the thinness and firmness of its texture; this, however, was not at hand, he was therefore obliged to rest satisfied with its best substitute, viz., folio sheets of large thin post.

The party now went vigorously to work; paper, paste, and scissors were immediately put in requisition. Sheets of paper were laid smooth on the table, and so arranged that each sheet overlapped its neighbour about half an inch. The skeleton of the kite was then placed upon them, and the paper was cut to its figure, a margin of about three-quarters of an inch having been left around it, except over the bow, where the margin was extended to an inch in width: this arrangement was for the purpose of allowing the paper to turn over the framework when pasted to it. This part of the work having been completed, and a sufficient time allowed for the drying of the paste, Mr. Seymour proceeded to fix the string, usually termed the "belly-band:" for this purpose two holes were bored through the lath in the centre of its breadth, the upper hole about a fifth part of the length of the kite from the top, the lower hole rather more than the same distance above its extremity.

The last and by far the most important point was to make the loop in the belly-band. If the kite be accurately constructed, the proper place for the loop may be easily found by extending the band, right or left, on the surface of the kite, and then marking the string at a point which lies in a line drawn from one end of the bow to the other; the loop must be made a little above this point. If the kite be now suspended by the loop, the two ends of the bow ought to preserve a balance, and the lower extremity should dip below the upper part of the kite.

As Louisa observed the extreme care with which her father adjusted this part of the machine, she inquired into its use.

"I was myself about to put the same question," said her mother; "for its adjustment would appear to require as much accuracy as that of the sash of a girl of sixteen."

Mr. Seymour informed them they would hereafter find that the steady ascent of the kite into the air entirely depended upon such accuracy. "Have you not seen, Tom," asked he, "a kite rise sideways, or plunge, as it is called?"

Tom said that he had often found his kites behave in that way, but he had attributed it to some defect in the tail.

"An error in the construction of the tail may certainly be occasionally the cause of such an accident, but it is more generally referrible to an improper position of the loop: if the kite plunges, you may conclude that this loop is placed too high; and should it whirl round in the air, you may infer that it is too low."

During this conversation, Mr. Goodenough entered the apartment; Tom was anxious to show him the newly-constructed kite, and while the party were asking the vicar numerous questions, Mr. Seymour observed that he would be more usefully employed in making bobs for stringing the tail, than in finding answers for their string of questions.

Mrs. Seymour and her daughters, with Tom and the vicar, were accordingly placed round the table, for the purpose of carrying this project into effect by a suitable division of labour. It was arranged that Mrs. Seymour should cut the paper, the vicar fold it, and Mr. Seymour tie the bobs on the string.

"How long ought the tail to be?" asked Tom.

"And of what shape should the papers be cut?" inquired Louisa.

"And at what distances are they to be placed from each other on the string?" said Mrs. Seymour.

"I will answer all your queries," said the father, "by giving you a dissertation upon this part of our machine."

"We shall now have an harangue," exclaimed the vicar, "as long as the tail itself. But pray proceed."

"The tail should never be less than twelve, and should it even amount to twenty times the length of the kite, its appearance in the air will be more graceful; this, however, must be regulated by the weight of the string, and by the length and thickness of the pieces of paper of which the tail is composed. The length of each ought to be about $3\frac{1}{2}$ inches, and $1\frac{1}{8}$ inch in

breadth, and it should be folded four times longitudinally. One of these bobs, as they are called, must be placed regularly at intervals of 3 inches."

"And with respect to the size of the wings?" asked the vicar.

"I should not recommend any wings: if the kite be well made, there cannot be any advantage from such appendages. As I have now answered your several questions, let us proceed with our work."

"But where is the paper?" asked Mrs. Seymour.

"*Apropos*," answered her husband, "the box in which the London toys were packed contains a quantity that will answer our purpose."

The box was accordingly placed on the table.

"Why, what a most extraordinary miscellany!" cried the vicar; "an *olla podrida* in the very first style of extravagance. I perceive," added he, as his eyes glanced from sheet to sheet, "we have here fragments of almost every description of literary and scientific works."

"The market," observed Mr. Seymour, "is supplied with waste paper from the catacombs of Paternoster Row, which may be truly said to level all earthly distinctions. Without intending any offence by a pun, my dear vicar, what a tale will this box unfold! I never open a magazine of this waste paper without feeling a deep sympathy for the melancholy fate of authors: to see the strange transmigrations and vile purposes to which their works are destined is really heartrending. That the lights of science should be consigned to the tallowchandler, the works of the moralist, so well calculated to purify the world, to the soap-seller—that such a book as 'Laennec on the Chest,' with Dr. Forbes's valuable 'Cases' in the bargain, should be packed off to the trunk-maker—are events which cannot fail to furnish food for melancholy reflection. Nay, more: I only yesterday learned, with horror, that a piece of fat bacon was positively sent here wrapped up in a page of 'Paris on Diet,' while a Cheshire cheese came encased in Kitchener's 'Chart of the Moon.'"

"Oh, shameful, shameful!" exclaimed the vicar; "but I can assure you that this unfeeling conduct on the part of the publishers has not escaped my notice and indignation, for I lately received a copy of Irving's Orations in an act of 'Much Ado about Nothing;' and, what was still worse, a little work on

'The Art of Prognosticating the Weather' was forwarded to me in a chapter of 'Daniel's Prophecies.'"

"These publishers must be exposed and punished, my dear Mr. Goodenough; or, if that be impracticable, it would be an object well worthy of the attention of the benevolent to prevent such cruel hurts to the sensitive feelings of authors—*genus irritabile*—by establishing a fund by aid of which an unsuccessful writer might purchase his own works as dead stock, and then reverently consign them to the flames."

"Why, truly, such a scheme would be classical—to consume the dead on the pile, instead of consigning them to the catacombs," replied the vicar.

"But, for the present, let us quit these melancholy reflections, and proceed with our occupation."

"If you form the tail of your kite with these papers," said the vicar, "it will have a knot of divinity, a knot of physic, a knot of logic, a knot of philosophy, a knot of poetry, and a knot of history."

"Never mind, my dear sir; you know that I am no gamester, but upon this occasion I will wager a copy of the best edition of Virgil that I shall be able to discover in many of these waste sheets some apposite allusion to the tail of which it is to form a part."

"Apposite allusion! impossible! as well might you attempt to connect the scattered leaves of the Sibyl: for example, here is an 'Epitome of Roman History.'"

"Very well," said Mr. Seymour; "and pray is not that curtail?"

The vicar dropped the paper in dismay: the treacherous design of his friend now, for the first time, flashed across his mind with a painful conviction, and he hastily retreated to a distant corner of the library, in order that he might find shelter from the pelting of a pitiless storm of puns, which he too clearly saw was about to burst on his devoted head.

On the vicar's retiring from the table, Mrs. Seymour approached the box, observing that it was now her turn to explore the Sibylline cave.

"Here," said she, "is a list of the prices of some newly published works."

"That," replied her husband, as he cast a sly glance at the vicar, "is retail. Pray proceed."

"We have next, I perceive, a prospectus for publishing all the speeches in the late Parliament."

"That is detail."

Here a deep groan from Mr. Goodenough arrested the progress of the proceedings, and threw the whole party into a fit of laughter. As soon as tranquillity was restored, Mrs. Seymour again dipped her hand into the box, and drew forth the fragments of a work on Real Property.

"That," said Mr. Seymour, "is entail. Pray cut it off, and give it to me."

"We have here," continued the lady, "the 'Memoirs of an Italian Bandit.'"

"Then prepare him for his fate; I have a noose quite ready for his reception."

"Here is a poem entitled 'The Rustic Muse.'"

"I will patronize it," said her husband; "and I warrant you that, under my auspices, the muse will soar to a greater height than she ever could otherwise have attained."

Thus did Mr. and Mrs. Seymour proceed, the one cutting paper, the other cutting jokes; nor did the former cease from stringing puns until he had finished stringing the tail.

"I must now conclude by making a knot that shall not be in danger of becoming untied in the breeze," said Mr. Seymour. "But stop—stop one moment; I still require one more piece of paper to complete my task, and let it be double."

"Here, then, is a piece of paper, which, from its texture, appears to be well adapted to your purpose. Let me see, what is it? I declare it is the title-page of an essay on 'Matrimony.'"

"Capital!" cried her husband; "a strange coincidence, truly. You have indeed furnished me with a knot that cannot be easily untied, however stiff may be the breeze. Hand it over to me, for it will afford a very legitimate finish, for that is usually considered the proper termination of every tale. But where is the vicar? What, ho! Mr. Goodenough!"

The reverend gentleman had concealed himself in a corner of the room, behind a large folio which he had placed on a desk before him.

"Upon my word," exclaimed he, as he pushed aside the huge folio, "your volatility, Mr. Seymour, is wholly inconsistent with the character of a scientific instructor."

"But, at present," replied Mr. Seymour, "I am engaged in

making a kite's tail; and surely flightiness ought not, upon such an occasion, to be urged to my disparagement. But honestly confess that I have fairly redeemed my pledge."

"Well, well, say no more upon the subject. Be silent, and I will acknowledge myself your debtor.

"'Est et fideli tuta silentio
Merces'—

as Horace has it."

"And you are already beginning to pay me off in instalments," said Mr. Seymour, "drawn as usual upon the classic banks of the Tiber."

The party shortly after this discussion separated. Mr. Seymour retired to his own room, the vicar proceeded to the church to bury a patient of Dr. Doseall's, and the children ran into the garden to enjoy their rural sports.

On the following day, before the wings of the lark had brushed away the morning dew, Tom and his sisters, buoyant with expectation, had descended into the garden in order to ascertain the state of the weather and the direction of the wind. But the sky was sad and calm; even the sensitive leaves of the trembling aspen hung motionless on their boughs, and testified the complete quiescence of the atmosphere.

"No kite-day this," sighed Tom with a countenance as gloomy as the morning clouds.

"Have patience," said Louisa; "the wind may yet rise, as it is only now six o'clock."

Thus did the minds of the children continue to oscillate between hope and despair until after breakfast, when they determined to seek the gardener, and hold a grave consultation with that acknowledged augur of the behaviour of the elements. He told them that showers might be expected, but he thought it probable that the wind might rise after midday; as the Siberian sow-thistle had closed itself the preceding evening, and the African marigold continued shut after seven o'clock in the morning, he thought there would be rain; but upon inspecting the "poor man's weather-glass," the *Anagallis arvensis*, or red pimpernel, two hours before, he had found it open, from which he concluded that the day would be fine.

"There, Louisa, it will be a fine day after all!" cried Tom.

"No, indeed," continued the gardener; "for when I went

just now to look again at the *anagallis*, which never deceives us, I found it had closed itself, so that rain is certain."

Nor was this opinion erroneous, for before Tom and Louisa could regain the mansion, the heavy clouds had begun to discharge their watery burden, and the rain continued in one incessant downpour for more than two hours. It then gradually abated, and the children, who had been anxiously watching the aspects of the sky at the library window, were relieved by the appearance of the vicar, whom they espied slowly winding his way among the dripping shrubs.

"We are under the influence of St. Swithin, vicar," said Mr. Seymour, as Mr. Goodenough approached the portico, "and I fear there is but slender hope of its becoming fair."

Very soon afterwards, however, some gleams of sunshine shot through rents in the dark clouds; and in the space of half an hour the sky brightened, and a brisk gale chased away the flying clouds, now no longer dark, but illumined by the full radiance of the sun.

"It is now quite fair, papa!" cried Tom, in a voice of triumph, "and there is a most delightful wind. Shall we at once proceed to the common?"

"Presently," answered his father; "the ground is yet extremely wet."

In the course of an hour this objection had been removed, and the party prepared to set off on their kite-flying expedition.

"Bring me the kite, and let me sling it properly over Tom's shoulder," said Mr. Seymour.

"I will carry the string," exclaimed Louisa: "how nicely it is wound round the stick!"

As the party walked forwards, the vicar asked Tom whether he knew from whence the name of the kite originated.

"A kite is a bird of prey," answered the boy, "which soars to a great height; and, from remaining stationary in the air, was, I suppose, thought to resemble the paper kite."

"That is a very good explanation," said the vicar; "or, perhaps, the toy may derive its name from the circumstance of its having been originally constructed in the shape of a bird of this description. In China the flying of kites is much more practised than in this country; and I understand that their shape is always that of some bird."

"In the London toy-shops," replied Mr. Seymour, "you may

meet with kites of such forms, as well as of many other fantastic shapes. I remember seeing some years ago a kite which resembled a man. It was made of linen cloth stretched on a light frame, so constructed as to resemble the outline of the human figure, and it was appropriately painted. It stood upright, and was dressed in a sort of jacket; the arms were disposed like handles on each side of its body; and the head being covered with a cap, terminating in an angle, facilitated the ascent. The machine, which was 12 feet in height, could be folded double by means of hinges adapted to the frame, so as to render its transport easier. The person who directed this kite was able to raise it, though the weather was calm, to the height of nearly 500 feet; and when once raised, he maintained it in the air by giving only a slight motion to the string. The figure was thus made to exhibit movements like those of a man skating on the ice. This novelty did not fail to attract a number of spectators."

"I believe, however," observed the vicar, "that the form in which the kite is commonly constructed is the one best calculated for the purpose."

"I wonder," cried Tom, "when the kite was first invented?"

"As to that," answered Mr. Goodenough, "I am unable to furnish you with any information. The pastime appears to be of very ancient date in China, and was, probably, first imported into Europe from that country."

"At what period, do you suppose?"

"Strutt, who was very assiduous and correct in all his antiquarian researches, was of opinion that its introduction into England could not be dated further back than two centuries."

The party had by this time reached Overton Heath, and the kite was impatiently fluttering in the breeze, while Tom was eagerly engaged in unwinding its streaming tail and preparing the paper machine for ascent.

"Is the string fixed to the belly-band?" asked Mr. Seymour.

"All is ready," replied the vicar; "and I will hold it up while Tom runs with it against the wind."

"There is not the least occasion to raise the kite from the ground," observed Mr. Seymour: "let its point rest on the grass, and place its tail in a straight line in front of it; I warrant you it will rise as soon as Tom begins to run."

Tom immediately set off, and the kite rose majestically into the air.

"Give it string—give it string!—gently, gently—now stop; there is no occasion for your running any farther, but let out the cord as long as the kite carries it off vigorously and keeps it fully stretched; but wind it up the moment the tension is relaxed."

"The kite is now at a considerable height," observed Tom: "but look at the string, how bent it is! I have repeatedly endeavoured to pull it straight, but without success."

"How could you have expected to succeed in the attempt? Consider the weight of such a long line of string. But, as you now appear to have let out the whole of your string, suppose you allow the kite to enjoy its airing, while we proceed to consider the philosophy of its ascent, and the nature and direction of those forces by which it is effected."

"The kite pulls so amazingly hard," cried Tom, "that unless I fix the string securely around the tree, we shall run the chance of losing it."

"I am well aware of the force it exerts," replied his father. "Dr. Franklin has said that, with a good kite, a man unable to swim might be sustained in the water, so as to pass from Dover to Calais; but I agree with him in thinking that a steamboat would be a much safer as well as a pleasanter mode of conveyance. But can you tell me, Tom, what advantage is gained by your running with the kite?"

"I suppose that you thus obtain more force from the wind."

"Certainly. Action and reaction are equal. By running, therefore, with your kite against the wind, you move it against the air, and thus produce a reaction, which is equal to the force with which you pull it, so that your running has the same effect as a wind of like velocity. When the wind is high, and its action is not intercepted by surrounding objects, there cannot exist any necessity for such an expedient. Let us now explain the ascent of the kite; for we have as yet merely considered the effect of increasing the wind upon its surface; we have next to inquire how the wind operates in raising it in the air."

"Yes," cried Tom; "do pray come to that, for I am much puzzled to understand how the wind can keep the kite up so steadily when everything else is blown about. But I suppose that the tail and the string have something to do with it?"

"Undoubtedly they have, as you will presently learn," replied Mr. Seymour; "but we must begin by considering the action

of the wind. You remember when I adjusted the noose in the belly-band, I stated that much depended upon this part of the apparatus. You now perceive that it influences the angle which the kite forms with the horizon, and I am about to prove to you that the kite's ascent is connected with this angle; but, in order to render my explanation intelligible, I have prepared a

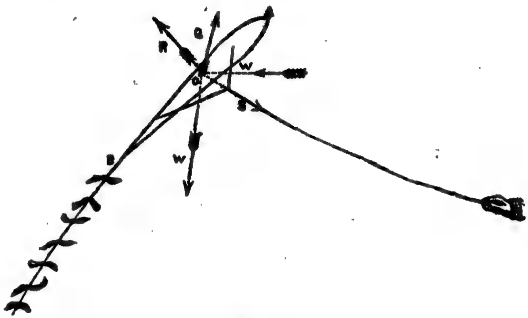


Fig. 91.

diagram (Fig. 91), to which I am desirous of directing your attention. I have here represented your kite, at A C, as seen edgeways when it is rising from the ground; S is the string, and we shall suppose that the wind has been collected into one current, which I have represented by the line W. You perceive that the wind strikes the surface of the kite obliquely, and I have no doubt you could tell me what happens in such a case."

"The particles of the air will, I suppose, behave like so many balls thrown against a wall—that is, they will be reflected?"

"Quite right; and you will of course remember that the resistance of the kite may be considered as the force which thus changes the direction of the wind's motion, and the necessary reaction of this force will be directed perpendicularly to the surface of the kite, as at O R. But there is another force acting on the kite—namely, the tension of the string. When these two forces are directly opposed the kite will cease to rise, but in the position indicated in my drawing they would have a resultant directed along O Q, and this force it is which acts to raise the kite."

"Then if I quickly slacken the string," said Tom, "the kite

begins to descend, or if rising, it at least ceases to do so, at the same time that it is carried away horizontally."

"That is because your act simultaneously diminishes the resistance of the kite to the wind and the tension of the string, and therefore the resultant force along O Q is likewise diminished."

"I am sure," said Tom, "that I perfectly understand your explanation, and I think I may also answer for my sister; but you have not yet told us anything about the tail. I suppose, however, that it acts like the rudder of a ship or the tail of a bird."

"Before I answer that question, let me inform you that the tail of a bird has not the least resemblance, in its action or uses, to the rudder of a ship."

"I always thought," said Tom, with some surprise, "that the bird was enabled to direct the course of its flight by the motion of its tail."

"That is a popular but very erroneous opinion," replied his father: "the tail cannot perform the office of a rudder, since it never changes its situation with the direction of the bird, as the rudder does with that of the ship. Its principal use seems to be to keep its body poised and upright."

"How, then, is the bird enabled to alter the course of its flight?" asked Louisa.

"It can easily turn, either to the right or left," answered Mr. Seymour, "by flapping the opposite wing with increased force, just as a boat is turned about to the right by a brisk application of the left oar."

"But you have not yet answered Tom's question," said the vicar. "Of what use is the tail of the kite? Does it assist its ascent, or is it merely an appendage of ornament?"

"In the first place, it keeps the head of the kite to the wind; and, in the next, it lowers its centre of gravity, and throws it towards its extremity, thus acting as ballast, which not only prevents the chance of the machine being upset in the air, but so poises and regulates the position of the kite as to maintain the angle which it is necessary for the string to make with the surface."

"But could not that be done," asked Tom, "by hanging a small weight to the bottom of the kite?"

"You must observe," replied Mr. Seymour, "that the tail acts in a manner which a simple weight cannot: for instance,

you see that the wind blows the tail into a curve, so that its pull on the lower extremity of the kite is by no means vertical, but in a direction which tends to keep the kite in a slanting position."

Tom, who was now becoming imbued with the spirit of the experimental philosophy, suggested that they should haul in the kite, and try the effect of substituting for the tail with the paper bobs, a piece of string with a slight weight at the end. This was accordingly done, the result verifying Mr. Seymour's statement; for though the kite did just rise from the ground when Tom ran with it very fast, it descended again the moment he stopped, and yet it was up long enough for the party to see that it flew almost in a vertical position. Tom then said he should like to know what would happen if the number and size of the bobs were much increased.

"In that case," said Mr. Seymour, "the tail would be carried out by the wind beyond the kite, so as to incline it too much towards the horizontal position."

Mr. Goodenough here inquired what might be the most advantageous angle for the kite to form with the horizon, in order that the paper machine should rise to the greatest altitude.

"If the wind be horizontal, it is evident that the more vertical the position of the kite, the greater the extent of surface it opposes to the wind, but at the same time the less will be the upward direction of the resultant pressure. At an inclination of about 55° these opposite effects so compensate each other that the upward force is at its maximum."

Tom here interrupted the dialogue by expressing a regret that he should have been provided with so small a quantity of cord.

"I do not believe, my dear boy, that any advantage could be gained by an additional quantity of string," said his father.

"Is there, then, any reason why the kite should not ascend, even above the clouds, provided that my string were sufficiently long and strong?"

"Yes, indeed, there is a most unanswerable reason. Remember that the kite is made to rise by the operation of two forces—the one afforded by the wind, the other by the action of the string. Now, it is quite evident that when the weight of the string, added to that of the kite itself, becomes equal to the force of the wind acting upon the surface of the machine, a general balance or equilibrium of forces will be established, and the kite can no longer continue to ascend."

"Will it, then, remain stationary under these circumstances?" asked Louisa.

"It must do so unless the force of the wind should abate, for the weight of the kite, the force of the wind, and the action of the string exactly balance each other."

"But if the twine should snap?" said Tom.

"Then one of these three forces would be withdrawn, and the kite could no longer be sustained."

"I trust that such an accident is not likely to happen to our kite; but if it should we could easily recover the kite, that is one good thing, for it is hovering over the open field at the end of the heath."

"If you imagine that the kite, under such circumstances, would fall upon the spot directly under it, you are much deceived. Recollect that the kite would then be abandoned to two forces—the wind and its own gravity; and you will perceive that under such circumstances it must obey both of them, and would fall in an intermediate or diagonal direction."

"There is one circumstance connected with the kite, to which, papa, you have not alluded," said Tom. "But I think it must have some effect in slightly modifying the action of the air. You have considered the surface of the kite as quite flat; whereas, when it is flying, the wind blows back the paper very much, and the surface slopes away on either side of the central upright stick."

"I am glad you have taken notice of this circumstance, and have reminded me of it," replied Mr. Seymour. "The inclination of the sides of the kite does not, of course, interfere with the general theory of its ascent, which I have already given you. But this inclination is of the greatest importance in practice. It is this which keeps the kite steady before the wind, to which it would otherwise be apt to present its edge—in fact, it would be quite impossible to make a kite with a perfectly flat surface fly at all. But come, Tom, let me hear if you can explain how it happens that the inclination of the sides of the kite should keep it steady to the wind. Here are paper and pencil."

Tom drew two lines,  B A, B C, to represent the inclined surfaces of the kite; and then said that when these surfaces were equally inclined to the wind blowing in the direction

D B, the resultant forces would exactly balance each other, and the kite be steady. For if, from any cause, the kite were turned round, so that one surface, as A B, became more inclined to the wind than the other, B C, thus: 

then B C would present a larger effective surface to the wind, the perpendicular pressure upon it being greater than that upon A B, the kite would be turned round until these pressures again became equal.

"Come," said the vicar, "before Tom draws down his kite let us send up a 'messenger.'"

"What may that be?" asked Louisa.

"A piece of paper or pasteboard, which, on being placed upon the string, is blown along the line up to the kite."

The messenger was accordingly prepared, and being placed upon the string, it ascended as Mr. Seymour had anticipated. While this operation was in progress, the vicar stood earnestly gazing upon the kite, and at length burst forth in the following animated soliloquy:

"Assuredly this must be acknowledged as a most beautiful and imposing toy! Fastidious or insensible must be that person who does not feel exhilarated as he gazes on the kite proudly floating under the canopy of heaven, and reflecting the crimson glow of the setting sun, even after that luminary has ceased to cast the departing beams of its rosy light athwart the darkening plain!"

"Has the kite ever been applied to any useful purposes?" asked Tom.

"Certainly," answered his father. "It was by means of the kite that Dr. Franklin was enabled to demonstrate the identity of electricity and the cause of lightning, and thus to disclose one of the most awful mysteries of nature."

"Pray do tell us something about this electrical kite, papa," said Louisa.

"Not at present, my dear; it would divert us too much from the subjects in which we are engaged: at some future period I shall have much pleasure in introducing you into these fairy regions of philosophy. But there can be no objection to my showing you a little sketch I made in my study during the morning (Fig. 92). It represents Franklin drawing the electric spark from the end of the string of his kite, and it may serve to

Fig. 92.

keep alive in your memories the circumstance that the kite has been the means of verifying a very important conclusion."

"I just now remember reading in Miss Edgeworth's 'Harry and Lucy,'" said Louisa, "something about a kite and Pompey's Pillar."

"I am glad that you have reminded me of that story," replied Mr. Seymour: "I will relate it to Tom, who has not, I believe, yet read the book. Some English sailors laid a wager that they would drink a bowl of punch on the summit of Pompey's Pillar. Now, that pillar is almost a hundred feet high, and it is quite smooth, so that there was no way of climbing to the top, even for sailors, who are such experienced climbers; so they flew their kite exactly over the pillar, and when it came down on the opposite side the string lay across the top of the capital. By means of this string they pulled a small rope over, and by this a larger one that was able to bear the weight of a man; a pully

was then fastened to the end of the large rope and drawn close up to the upper edge of the capital, and then, you perceive, they could easily hoist each other up. They did more, for they hoisted the English flag on the top, and then drank the bowl of punch, and won their wager."

"That is a very good story," said the vicar; "but I cannot help regretting that so much ingenuity and labour should not have had a nobler end to accomplish."

"There is some truth in that observation," said Mr. Seymour, "and I will, therefore, relate another story which shall be more congenial to your heart, and in which the kite will present itself in a more interesting point of view; for, instead of enabling the sailors to drink a bowl of punch at an altitude otherwise inaccessible, we shall find it engaged in rescuing them from the horrors of shipwreck."

"Pray proceed, papa."

"No, my dear; upon second thoughts, I think it will be better that we should postpone the story until your return to the Lodge, when you shall read the account in 'Harry and Lucy.' But it has just occurred to me that I have been told that some of those marvellously lofty chimneys of steam-engine furnaces which you see in manufacturing districts, have been ascended for the purposes of repairs by precisely the same means as that employed by the sailors to reach the summit of Pompey's Pillar. On our return, I may this evening, or perhaps to-morrow more conveniently, take the opportunity of showing you some experiments in illustration of other cases of reaction occasioned by the air."

"Shall we not return immediately?"

"No, my child; it would not be in my power to attend you at present. Mr. Goodenough will now accompany me on a visit to Major Barker, and do you remain and enjoy the amusement of your kite."

CHAPTER XXI.

A sheaf of peacock arrows, bright and keen,
Under his belt he bare full thriftily.
Well could he dress his tackle yomanly;
His arrows droopèd not with feathers low,
And in his hand he bare a mighty bow.

TOM'S holidays were now approaching their close, as on the following week he would be required to resume his place at school. There still remained, however, a few bright days, during which he was to share the endearments of the affectionate circle at Overton Lodge; and it was upon almost the last of these that we might have seen him, in the company of his father and Mr. Goodenough, stepping across the lawn towards the terrace, where the younger girls had for some time been amusing themselves by playing at shuttlecock and battledore.

"Papa," exclaimed Fanny, "I have been considering whether there is any philosophy in the game of shuttlecock."

"There are two circumstances connected with its flight," re-

plied her father, "which certainly admit of explanation upon scientific principles, and I should much like to hear whether Tom can explain them. The first is its spinning motion in the air; the second, the regularity with which its base of cork always presents itself to the battledoor, so that after you have struck it, it turns round, and arrives at your sister's battledoor in a position to be again struck by her, and sent back to you."

"I perfectly understand what you mean; but I really am not able to explain the motions to which you allude," said Tom.

"The revolution of the shuttlecock about its axis entirely depends upon the impulse of the wind on the oblique surfaces of its feathers; so that it is often necessary to trim the feathers of a new shuttlecock before it will spin."

"I understand you, papa: the force of the wind, by striking the oblique feathers, is resolved into a perpendicular force, as you explained to us when we considered the action of the wind upon the kite."

"Exactly. And having settled this point, let us consider the second, namely, how it happens that the cork of the shuttlecock always presents itself to the battledoor."

"I should think," said Tom, "that the cork points to the battledoor for the same reason that the weathercock always points to the wind."

"Admirably illustrated!" exclaimed his father: "the cork will always go foremost, because the lighter feathers, presenting to the air a surface far greater as compared with their mass, will be more retarded in their progress. While we are upon this subject, I will introduce to your notice some contrivances which operate by this same principle. In the first place, there is the arrow: can you tell me, Louisa, the use of the feathers which are placed round its extremity?"

"To make its head proceed foremost by rendering the other end more sensible to the resistance of the air," replied Louisa.

"Very well answered: that is unquestionably one of the objects of furnishing an arrow with wings; but there is also another —that of steadying its progressive motion by *rifling* it, or causing it to revolve very rapidly round its axis. If you will look at this arrow, you will perceive that the feathers are placed nearly, but not quite, in planes passing through it. If the feathers were exactly in this plane, the air could not strike against their surfaces when the arrow is in motion; but since they are not placed

perfectly straight, but always a little aslant, the air necessarily strikes them as the arrow moves forward. By the force thus produced the feathers are turned round, and with them the arrow or reed, so that a rotatory motion is generated; and the velocity of this motion will increase with the obliquity of the feathers up to a certain point, beyond which a further increase of the angle of their inclination to the axis of the shaft would diminish the effect. You will, therefore, observe that, in order to enable the feathers to offer the necessary resistance to the air, they must possess a certain degree of stiffness or inflexibility."

"It was on this account," observed the vicar, "that Roger Ascham, and other skilful artists in the days of archery, preferred, for pluming the arrow, the feathers of a goose of two or three years old, especially such feathers as drop of themselves; and the importance of this choice is confirmed by an observation of Gervase Markham, who says that 'the peacock feather was sometimes used at the short butt; yet seldom or ever did it keep the shaft either right or level.'"

"That is intelligible enough," said Tom: "the feather of the peacock is so flexible as to yield to the slightest breath of air. But now, papa, as we are upon the subject of the arrow, do pray explain to us the action of the bow."

"I shall readily comply with your request before we part; but I am desirous at present of following up the subject before us, and of taking into consideration some other contrivances which owe their motions to the action of the air upon oblique surfaces."

"Suppose," said the vicar, "you explain to them the action of the wind upon the sails of the mill."

"I should like to hear something about the windmill," observed Tom; "and perhaps Mr. Goodenough can tell us who invented the machine."

"The invention is not of very remote date," replied the vicar. "According to some authors, windmills were first used in France in the sixth century; while others maintain that they were brought to Europe in the time of the Crusades, and that they had long been employed in the East, where the scarcity of water precluded the application to machinery of that more powerful agent."

"I had intended," said Mr. Seymour, "to enter fully upon the subject of the windmill; but I should require several models which are not yet in readiness, and as Tom's holidays have

nearly passed away, I must postpone the examination of the mill to some future opportunity, and content myself, at present, with an explanation of its sails. To understand why these sails revolve by the force of the wind, we must have recourse to the notion of resolved forces. It is evident that if a mill exposed directly to the wind had the planes of its sails perpendicular to the axle, they would receive the wind at right angles to their surfaces, and the impulse would simply thrust the axle longitudinally. But when the planes of the sails are set so that they slope a little away from the direction of the wind, the impact of the latter gives rise to a force which, resolved in the direction of rotation, impels the sails, and thus the axle is carried round; for the four sails are all set obliquely in the same direction, and unite their effects. But if you will now come with me into the dining-room, I shall be able to exhibit to you an amusing toy which acts by the same principle as the windmill. I require some one to bring me the piece of pasteboard which lies on the library table."

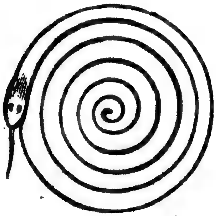


Fig. 93.

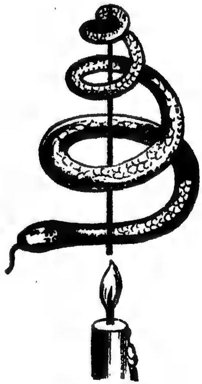


Fig. 94.

The pasteboard was produced, and Mr. Seymour drew upon it a spiral, similar to that represented in the annexed figure (Fig. 93). The spiral was then cut out, and extended by raising the centre above the outer coils. It was now suspended upon a knitting-needle by applying the centre or summit of the spiral

to the point, in a manner which will be quite obvious from an inspection of Fig. 94, where the spiral is shown as it appeared when Tom had painted it afterwards, so as to represent a serpent. The whole was now placed some distance above a lighted candle, and the little machine, to the great delight and astonishment of the children, soon put itself in motion, and turned without the interference of any apparent agent. The agent, however, was the air, which, being rarefied by the contact of a warm body, ascended and thus produced a current. The sketch in Fig. 94 will render the experiment intelligible to the reader.

The vicar observed that, to him, the toy was perfectly novel, although he remembered seeing what he now supposed must have been a similar contrivance, but the action of which he had, until that moment, always considered as the effect of clockwork.

"And what was that?" asked Mr. Seymour.

"A kind of revolving serpent, which I noticed in a shop window in London; but it was doubtless nothing more than a spiral, so painted as to resemble that reptile, and which owed its motion to the action of air heated by a lamp placed beneath it."

Mr. Seymour produced another toy depending for its operation upon the reaction of the air upon oblique surfaces. It was the now well-known flying top, which, being provided with projecting vanes set obliquely to the axis, rises in the air when it is put in motion, and for a short time spins against the ceiling of the room. The action of the toy was explained to the children, and some conversation took place between the seniors relative to flying-machines.

Mr. Seymour then stated that he had ordered from London a set of bows, arrows, and other implements of archery, which he was about to present to Tom and Louisa as a mark of his gratification at the interest they had manifested, and the progress they had made in their scientific studies. He accordingly sent for a box which had arrived that morning, and opening it, displayed the implements, the view of which called forth a shout of delight from the juveniles.

"I think," observed Mr. Goodenough, "that I might accompany your gift with some account of archery, or the art and exercise of shooting with the bow and arrow."

"That we shall be highly gratified to listen to," replied Mr. Seymour.

"The bow is the most ancient and universal of all weapons,"

Mr. Goodenough accordingly proceeded; "it has been, and still is, used amongst even the most barbarous and remote nations."

"Its earliest application was probably for the purpose of obtaining food," observed Mr. Seymour.

"Your conjecture has the weight of testimony," replied the vicar: "when Isaac sent Esau to the forest, he said, 'Take, I pray thee, thy weapons, thy quiver, and thy bow, and go out to the field, and take me some venison.' There can be no doubt that the bow and arrow were employed for the purpose of killing animals for food from the earliest times; but their principal interest is derived from their military applications. I will therefore confine myself to the use of the bow in England as a weapon of war. The bows used in England were of two kinds, the common or long-bow, and the cross-bow. The former does not require any description from me; the latter, the *Arbalet*, as it was called, consists of a steel bow fastened upon a stock, and is discharged by means of a catch, or *trigger*, which probably gave rise to the lock upon the modern musket.

"Cross-bows were first used in England by the Normans at the battle of Hastings; and a *quarrel* or *bar-bolt*, the name given to the arrow of the long-bow, was the immediate cause of Harold's death. Under Edward IV. an ordinance was made that every Englishman and Irishman dwelling in England should have a bow of his own height, to be made of yew, wych, hazel, ash, or any other seasonable tree, according to their power. By Henry VII., and his son Henry VIII., the use of the cross-bow was entirely forbidden; and a penalty of £10 was to be inflicted on every man in whose house one might be found. From this time cross-bows seem to have been chiefly used for killing deer. Henry VIII. compelled every father to provide a long-bow and two arrows for his son at seven years old. Edward VI., Elizabeth, and James all encouraged archery. John Lyon, who founded Harrow School in 1590, two years before his death drew up rules for its direction, whereby the amusements of the scholars were confined to 'driving a top, tossing a hand-ball, running, and shooting.' The last-mentioned

Fig. 95.

diversion is in a manner insisted on by the founder, who requires all parents to furnish their children with 'bow-strings, shafts, and tresters to exercise shooting.' A silver arrow used some years ago to be shot for by the boys of that school."

The vicar concluded, and received the thanks of the party for the interesting information he had afforded them. He was prepared, however, to supplement his antiquarian discourse by graphic illustrations; for he produced from his pocket-book copies of two prints from old drawings, in one of which the military use of the bow and arrow was indicated; while the other depicted a sportsman of the period employing a cross-bow. As the quaint manner in which the ancient limner had drawn his subjects considerably amused our young friends, we reproduce these designs for the benefit of our readers in Figs. 95 and 96.

Fig. 96.

"There is one circumstance connected with the military history of the long-bow," said Miss Villiers, "which has somewhat surprised me, and that is, why it should so long have continued in estimation after the use of gunpowder."

"That circumstance," replied Mr. Seymour, "will cease to astonish you when you remember that until the last century muskets were very unwieldy instruments: they were never used without a rest, had no bayonets, and could not be so frequently discharged as those of more modern times. But I perceive that the children are impatient to try their skill with their new instrument, so let us walk out."

"Now, Tom," said Mr. Goodenough, "we must have an object. Come, try whether you can hit yonder gatepost. Take your bow, and here is an arrow."

Tom took the bow, and, placing the arrow on the string, was about to draw the latter, when the vicar exclaimed,

"Stop! stop! you must pull back your hand to your right ear, in order to shoot the arrow; whereas you have placed the bow directly before you, and are about to return your hand to the right breast."

"I thought," said Tom, "that was the proper position, for I remember reading of the Amazonian women, who are said to have parted with their right breasts, lest they should prove an impediment to their using the bow."

"I do not mean to assert," replied the vicar, "that there is not ample classical authority for your proceeding. The Amazons undoubtedly shot their arrows in such a position; and so, in truth, did the primitive Grecians; although the ancient Persians drew the arrow to the ear, according to the fashion of later ages, and which I greatly prefer for its superior convenience."

Mr. Seymour showed his son the attitude preferred by the vicar, by himself drawing the bow in the manner represented in the annexed sketch, Fig. 97.

Fig. 97.

The party now amused themselves for some time, each shooting in his turn at the mark which was chosen for the trial, and with a success which, considering it was their first attempt, the vicar declared to be "quite marvellous."

At the conclusion of the sport, Mr. Goodenough informed his friends that parochial duties required his attendance at the vestry; but Mrs. Seymour, who joined the party on the lawn just as Mr. Goodenough was taking his leave, told him that, before he quitted them, she had a piece of news, which had lately reached her, to communicate to him.

"No bad news, I trust."

"No; but it concerns yourself, and I fear may occasion you some surprise and regret. You are about to lose your old faithful servant Annette."

"Annette! Why, my dear madam, you really do not mean to say that Annette has fallen ill since I left the vicarage this morning? Surely Dr. Doseall cannot be in attendance upon her?"

"No, no. But I hear that Annette is going to be married."

"Married! impossible! Annette is too old and sensible. Depend upon it that she will not desert her master."

"I assure you that she is engaged to Jacob, the major's valet."

"My dear madam, you are jesting. What! Annette desert her master, and for a valet! And yet I remember having frequently seen the fellow at the vicarage of late. It may be true—it is possible—it is probable—nay, I begin to think it very likely. Oh! the hussy, the ungrateful hussy! But I will instantly summon her before me, and learn the truth or untruth of this report."

"You had better first inquire of Miss Ryland," said Mrs. Seymour, "for I strongly suspect that she may be able to afford you some information upon the subject."

The vicar immediately set off at a quick pace; his anger accelerating his velocity, and his velocity, in return, increasing his rage, just as the fire in a chafing-dish is blown up by running with it. Such at least was the image which his own conduct upon this memorable occasion served to call up in his mind, when he was afterwards speaking of the incident in conversation with Mr. Seymour, for he found an illustrative quotation in the words "*cursu ventilat ignem.*"

Leaving the vicar to pursue his wrathful course, we must turn our attention to an incident which occurred at the Lodge the same afternoon. Such of our readers as are at all familiar with the course of tales and romances, will probably have already divined the significance of that profound impression which the musical performance of Miss Villiers produced upon Major Barker. By a few commonplace inquiries addressed to Mrs. Seymour in the course of conversation, he found that his perceptions of resemblances in voice and music had not been unfounded, and that Laura Villiers could be no other than the only daughter of his quondam flame. But the effect of this discovery on the major's part was speedily lost in a greater surprise. For when Mrs. Seymour, after speaking of Laura's excellences, incidentally mentioned that she was engaged to a young and talented artist named Lovell, the effect on the major was electrical.

"Lovell did you say, and an artist?" he exclaimed, eagerly. "Is his Christian name Henry?"

"It is," replied Mrs. Seymour.

"Then it is he. Good heavens! and the daughter of Isabella Manners is actually engaged to my nephew!"

"Is it possible," ejaculated Mrs. Seymour, "that Henry Lovell is Major Barker's nephew?"

"He is indeed, madam," replied the agitated major; "and it is only this morning that I have written to ask him to come to Overton. Pray excuse my abruptness, you shall shortly learn the cause of it; but the story is a long one."

A prolonged and interesting conversation, relative to Lovell and Laura, now ensued between the major and Mr. and Mrs. Seymour, the information and explanations on either side affording the highest degree of satisfaction. The incidents following these strange and unexpected recognitions we must leave to be indicated in the next chapter.

CHAPTER XXII.

Our lovers, briefly be it said
Wedded as lovers wont to wed,
When tale or play is o'er.

THE great Wizard of the North has compared the course of a narrative to the progress of a stone rolled down-hill by an idle truant boy. At first the stone moves slowly, avoiding by inflection every obstacle of the least importance; but when it has attained its full impulse, and draws near the conclusion of its career, it smokes and thunders down, taking a rood at every spring, clearing hedge and ditch like a Yorkshire huntsman, and becoming most furiously rapid in its course when it is nearest to being consigned to rest for ever. "Even such is the course of a narrative: the earlier events are studiously dwelt upon; but when the story draws near its close, we hurry over the circumstances, however important, which your imagination must have forestalled, and leave you to suppose those things which it would be abusing your patience to relate at length."

Let the reader accept these words as an explanation of, and an apology for, the rapidity with which we now hasten over the events that bring our tale to its close. Need it be said that the major recognized his nephew as his heir; that he sanctioned his union with Laura Villiers; and that, after the manner of rich uncles, he made a splendid settlement? Nay, more: before the marriage, the major purchased in the neighbourhood of Overton a compact little estate and residence, which happened opportunely to be offered for sale; and he declared that this should be his nephew's country home, upon the sole condition that his old uncle should for a few months in the year share in its rural delights. Nothing, therefore, remained but to appoint the day on which Laura Villiers should bestow her hand upon Henry Lovell, thereby completing his happiness, and perfecting the satisfaction of the major. We might plead the dramatic unities that confine our scene of action to Overton, as a pretext for dispensing with the description of the ceremony itself, which took place elsewhere; but we may at once frankly confess that the powers of our pen would, in any case, have proved inadequate to the occasion. As, however, it was determined to celebrate the arrival of the young couple at Oakwood Park, their future residence, by a rural *fête* at Overton, we have yet to recount the occasion and manner of this festival.

First, a word as to our worthy vicar, whom we left at the end of the last chapter in a state of mental effervescence foreign to his usually serene breast. But the propitious events which had occurred in the interval had so calmed his spirit, that his habitual good-nature asserted itself; and he announced that as, notwithstanding all his remonstrances, Annette was determined to marry Jacob Thompson, the major's valet, he had promised to perform the ceremony himself, observing that, "as Virgil has it, '*Connubio jungam stabili.*'"

"As it is quite settled," said the major, "by all means let them marry; and I think matters may be so arranged as that you shall not be deprived of the services of your faithful housekeeper."

The *fête* by which Overton was to celebrate the arrival of Henry Lovell and his blooming bride in their new home was a project of Major Barker's.

"I would gladly diffuse," said he to the vicar, "a portion of my happiness over the neighbourhood in which it is my inten-

tion to pass my future days. Listen, therefore, to the plan which I have devised for carrying this into effect. I design to give a public entertainment upon a scale rarely witnessed in a country place."

"An entertainment!" muttered Mr. Goodenough, whose countenance afforded anything but encouragement to such a scheme; for our vicar was as little disposed to enter into the major's festive ideas as he was at the outset, into Mr. Seymour's plan of scientific instruction.

The major, however, saw plainly that the vicar might be made to approve of, or dissent from, any plan, by a dexterous appeal to classical and antiquarian authority. He therefore determined to use this as a talisman for transforming that excellent man into an active agent in the accomplishment of his purpose; and accordingly he stated that he should desire to see the entertainment conducted with some regard to ancient usages.

The vicar's countenance brightened; but Mr. Seymour here interrupted the conversation by inquiring of the major the plan of those amusements which he proposed to provide.

"I would convert the elm meadow at Oakwood Park into a fair," replied the major, "wherein every species of amusement should be exhibited. I would engage that vagabond Punch, who, like a snail, travels about the country with his house on his back, to display his hereditary wit and mimic drolleries; tumblers, rope-dancers, conjurors, fire-eaters, and, in short, the whole merry train of Comus should be pressed into our service. After these exhibitions, the company might weave the mazy dance on platforms erected for their accommodation; orchestras might be arranged for music, and ornamented tents for refreshments. The vicar," continued he, with an arch smile, "might open the ball with the bride."

"Had I numbered a few Olympiads less, I might not have declined so flattering a distinction," replied Mr. Goodenough, evidently not displeased with the compliment.

"Find some classical authority for the measure, and let your age sanction the propriety of my proposals," said the major.

"Your suggestion merits attention—I have it, major. Socrates learned to dance very late in life, and Cato, with all his severity of manners, disdained not at the age of sixty to practise it. I will, therefore, comply with your desire, and certainly lead the bride down the first dance."

"How charming! how very delightful!" exclaimed Louisa. "But pray, papa, do allow Tom to return from school to witness all these amusements."

"Fear not," said the major; "I shall make that a condition, and I trust your papa will not refuse the request."

"Certainly not," replied the father; "I shall be glad to seize the opportunity for explaining to my children the various tricks they will witness, and the machinery by which the deceptions will be accomplished. Thus shall I convert that which, to the common eye, will appear as a scene of mere amusement, into a school of philosophy, and, in accordance with my favourite plan, 'turn sport into science.'"

"Upon my word, Mr. Seymour, you are quite an alchemist," said the major, "and extract gold from everything you can melt in your philosophical pot. You have already derived scientific information from the most miscellaneous and trifling amusements, and upon this occasion you will, no doubt, convert our very pies and puddings into instruments of instruction; thus verifying the old adage, that 'there is reason in roasting of eggs.'"

"I perceive that the major is not aware of the philosophy which suggested that adage," observed the vicar.

"Nor am I," said Mr. Seymour, "and pray, therefore, enlighten us upon that point."

"You doubtless know that there is a little air-bag at the large end of every egg, called the *folliculus aeris*, which, as we are told, is designed to furnish a supply of air to the growing chick. If, therefore, an egg be exposed to the temperature of hot embers, this air will be suddenly expanded, the shell will be burst, and its contents scattered in the ashes. To prevent such an occurrence, the careful housewife pricks the blunt end of the shell with a needle, so as to allow the expanded air to escape, and thus prevents the accident I have just explained. Thus it appears that there is reason, or philosophy, even in roasting an egg."

"Capital, upon my word!" exclaimed Mr. Seymour.

"Well, but, papa, we have interrupted the major in his delightful description; he had not concluded the account of his proposed *fête*," said Louisa.

"Pray go on," cried Mr. Seymour. "Let me see, where did you leave off? Oh! I remember, you were interrupted in an

ornamented refreshment tent, which I hope you intend to decorate with garlands and festoons."

"We must leave all that to the vicar," said the major; "he will, no doubt, display his classical taste in emblematical appointments. I shall terminate the festivities of the day by a grand display of fireworks, the arrangements of which may fall under my own more immediate direction. The vicar will perhaps allow me to proclaim him master of the revels; for he is, as we all know well, deeply versed in ancient customs, and I am especially anxious that every department should be conducted with classical taste."

"I willingly accept the office," said Mr. Goodenough, with a gracious smile, "since there is authority for my acquiescence. The Romans, in their entertainments, usually appointed a person, whom they styled king, and held responsible upon such occasions. I accept it also on a different ground—that my presence may check any undue enthusiasm of the people, and restrain the hilarity of the evening within the boundary of rational decorum."

The reader must have already observed that Mr. Goodenough was greatly influenced by the spell of antiquity, but we doubt whether he has any idea of the extent to which the reverend gentleman carried this enthusiasm. We may state one instance which will serve to illustrate this taste. His mince pies at Christmas were fabricated with an inflexible adherence to ancient authority: he maintained that the introduction of meat into their composition was a scandalous heresy; that the choicest productions of the East ought alone to be admitted, since the custom was originally intended to allegorize the offerings made by the wise men who came from afar to worship, bringing *spices*, etc. Indeed we may congratulate the rising generation at Overton on the circumstance of the offices of village schoolmaster and vicar of the parish not having centred in the same individual; for we have not the shadow of a doubt, so great was his veneration for ancient usages, but he would, as we are informed was the ancient custom, have whipped every child within his jurisdiction on the morning of Childermas Day, or that of the Holy Innocents, "in order that the memorial of Herod's murder of the Innocents might stick the closer."

Every arrangement at Oakwood Park had been completed on the day preceding that on which the return of the newly-married

pair was expected. The various show-booths had been erected by their respective owners with an expedition that might have put many a prouder architect to shame, and the marquees and temporary rooms for refreshments had been completed. The erection of a convenient stage for the display of fireworks had been accomplished under the sole guidance of Major Barker, who considered this department as belonging more immediately to himself.

We shall not, however, detain the reader with an account of the amusements and festivities, nor even with a relation of the great incident of the day—the arrival of the bride and bridegroom. It will be sufficient to state, in the language generally used upon such occasions, that the whole went off with great *éclat*, and gave universal satisfaction to the delighted guests.

The reader must now be contented to retire from the scene of frolic, and leave the villagers to the undisturbed enjoyment of their jollity. The major and his party returned to the house, where they remained until the hour approached at which the fireworks were to be discharged and the festivities of the day concluded.

Mr. Seymour accompanied his children to the stage erected for the pyrotechnic exhibition, in order that he might explain the construction of the fireworks before they witnessed them in action.

"Upon my word, the major has provided most liberally for our entertainment!" exclaimed Mr. Seymour, as he ascended the steps which led to the platform. "I declare there is a forest of rockets!—and what magnificent pinwheels, *tourbillions*, *marroons*, *pots des aigrettes*, *gerbes*, *courantines*, and Roman candles!"

"Are those paper cylinders, with long sticks, rockets?" inquired Tom.

"They are; and if you will attend to me, I will explain the principle of their construction. They have ever been considered as holding the first place amongst single fireworks, and deservedly so—not only on account of the splendid appearance they present when fired by themselves, but from their extensive application in increasing the beauty of other exhibitions. The rocket, you perceive, consists of a strong paper cylinder, which is filled with a suitable composition; it is crowned with a head, or 'pot,' as it is technically termed, charged with various materials, and

after the body of the rocket has been consumed, the 'pot' takes fire in the air, and throws out sparks, stars, and other decorations. You may observe that the head is made to terminate in a point, which greatly facilitates its passage through the air. The whole is affixed to a straight stick, which, like the rudder of a ship, makes it turn towards that side to which it is inclined, and consequently causes the rocket to ascend in a straight line."

"But, papa," observed Louisa, "all the rockets have not straight rods. See, there is one with a crooked stick."

"That is for the purpose of causing the rocket to ascend in the form of a screw."

"Are not those pin-wheels, which are elevated above the railing?" said Tom.

"Yes; they are pin or Catharine-wheels, and if you will look at them, you will perceive that they are of very simple construction—consisting merely of a long paper tube filled with inflammable matter, and rolled round a small circle of wood, so as to form a helix or spiral line."

"The circle of wood, I suppose, is pierced in the middle for the purpose of receiving a pin, by which the wheel is attached to the post?" said Tom.

"Exactly so; and the cause of their revolution is the same as that which produces the flight of the rocket."

"I think you told us, when speaking of the thaumatrope, it was the rapidity with which the flame revolved that occasioned the starlike appearance which is exhibited by this firework," observed Louisa.

"Undoubtedly, my dear: it cannot be otherwise."

At nine o'clock the commencement of the fireworks was announced by a shower of rockets. The music ceased, and the dancers, together with the spectators who had gathered around the platform, hastened to the spot, whither they were summoned by the sound of trumpets, to witness the pyrotechnic entertainment which was to crown the festivities of the day.

The little Seymours had been stationed by their father in the most favourable spot for seeing the exhibition, and highly were the major and his party delighted with the observations which fell from the intelligent children on the occasion.

"Observe, Louisa, the rocket as it ascends describes a parabola," cried Tom.

"Oh, how extremely beautiful! see, the head has burst, and

is discharging a number of brilliant stars! What is that red spark which is now falling to the ground, papa?"

"That is the ignited stick of the rocket," replied his father.

"Take care, Louisa, do not hold your face up," exclaimed Tom; "for as the rocket bursts over our heads, the stick may fall upon us."

"I scarcely expected such an observation from you, Tom,' said his father, "after the sensible remark you just made respecting the parabolic path of the rocket: do not you remember that when a projectile has reached its greatest altitude it will descend in a curve similar to that in which it ascended?"

"True, true," answered Tom; "I see my error: the stick must, of course, fall at a considerable distance from us."

"Look! look! There goes a *courantine:* how it ran along the rope!" exclaimed Louisa.

It is not necessary to enumerate the series of beautiful exhibitions which succeeded. We shall only add that the concluding firework was a Catharine-wheel of imposing splendour. After having repeatedly changed its device during its revolution, it at length exploded and threw out a group of serpents; the dense volume of smoke which followed this explosion having gradually cleared off, the appropriate motto of "FAREWELL!" appeared in brilliant letters of fire.

This word indicates that our task is done and our tale is told. For you, gentle reader, who have patiently followed us to this, the last page, we may venture to express a hope that some profit may remain after the volume is closed, and the personages of our story are remembered no more. In parting from them, and from you, kind reader, again we say—

> Farewell! a word that must be, and hath been—
> A sound which makes us linger; yet—farewell!

APPENDIX.

Note A.—MUSICAL PITCH.

The following table shows the numbers of complete vibrations per second, corresponding with notes of the natural gamut. By a complete vibration is to be understood the to *and* fro movement of the vibrating body; so that, in this sense, the ordinary seconds pendulum may be said to make *thirty complete vibrations* in one minute. The table is extended beyond the octave, in order to show the relations between successive octaves.

The Natural Gamut.

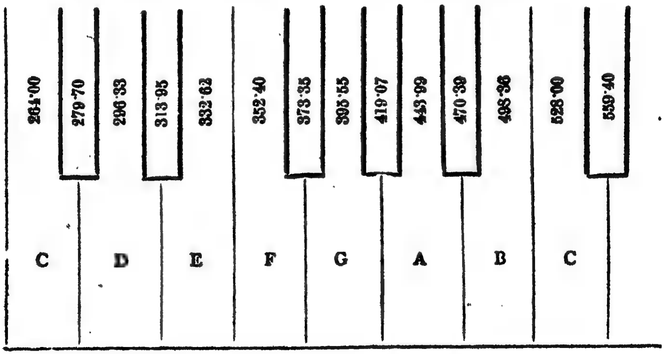
Notation

Names	C do_3	D re_3	E mi_3	F fa_3	G sol_3	A la_3	B si_3	C do_4	D re_4	E mi_4	F fa_4
Numbers of Complete Vibrations per second	264	297	330	352	396	440	495	528	594	660	704
Relative Numbers of Vibrations	24	27	30	32	36	40	45	48	54	60	64
Ratios to Vibrations of Key-note, do_3	1	9:8	5:4	4:3	3:2	5:3	15:8	2:1	2×9:8	2×5:4	2×4:3

The scale of notes in the above table belongs to what musicians term the key of C major; but, as every one knows, many other keys are made use of in music, so that, in fact, any note whatever may serve as the fundamental note of a scale. It will be found, however, that except when a C is made the fundamental note, the notes in the above table cannot furnish a complete series, in which the vibrations shall have the above ratios—a necessary condition of harmony. But by introducing between each pair of notes two additional ones, the numbers of whose vibrations shall respectively be to the lower note of the pair as 25 : 24, and to the higher as 24 : 25, the

resources of the musician are greatly extended, as he can then take any note of the twenty-two for the fundamental note of a gamut, in which the intervals shall follow in the same order, and with (very approximately) the same relative vibration-rates as in the gamut indicated above. Thus, there will be above C a note (*C sharp*), with a vibration-rate $= 264 \times \frac{25}{24} = 275$; and following that, another (*D flat*), with a vibration-rate $= 297 \times \frac{24}{25} = 281$.

The great number of notes which would thus be included within the compass of an octave would, however, cause much additional complexity in the construction of all musical instruments which, like the piano and organ, have fixed notes, and would also greatly increase the difficulties of the performer. But it has been found possible, by sacrificing a little of the strictness of the true harmonic ratios, to reduce to thirteen the number of notes comprised within the range of an octave. This is accomplished by a sort of compromise: pairs of notes, the vibration-rates of which differ but little, as in the case of *C sharp* and *D flat*, are replaced by a single note, which serves for either. The requisite compromise is most simply and uniformly effected by dividing the whole octave into twelve equal intervals (*semi-tones*)—that is, dividing it in such a manner that the vibration-rate of each note in the instrument may have throughout one and the same ratio to the vibration-rate of the next lower note; and the value of this ratio is, of course, the 12th root of 2, $\sqrt[12]{2} = 1 \cdot 0594 \ldots$, since the highest note of each octave must have just twice as many vibrations as the lowest. The absolute numbers of complete vibrations corresponding with the middle octave of a piano, in which this plan of "*equal temperament*" is adopted, appear below. The same note C, executing 264 vibrations per second, which is the first in the foregoing table, occupies in the following one a similar position:



Commencing from any one *fundamental note* of a series of notes thus related, and ascending by successive intervals of *two tones, one semi-tone, three tones, one semi-tone*, we obtain a set of sounds which have so nearly the relations of the notes in the natural gamut, that even a trained ear can scarcely detect any defect from perfect harmony. A series of notes following each

other with the intervals just mentioned, constitute what is termed a "key;" but by selecting the intervals in the order—*one tone, one semi-tone, two tones, one semi-tone, two tones*—sets of notes are obtained possessing harmonic relations, yet somewhat different from those of the natural gamut, and constituting what are termed "*minor keys,*" because in these the interval between the fundamental note and its third being only three semi-tones, is less than in the other, or major scales, where it is four semi-tones. Writing *t* for the interval of a tone, and *s* for that of a semi-tone, these gamuts ascend thus:

Major Key: 1—*t*—2—*t*—3—*s*—4—*t*—5—*t*—6—*t*—7—*s*—8
Minor Key: 1—*t*—2—*s*—3—*t*—4—*t*—5—*t*—6—*t*—7—*s*—8

The ratio of the vibration-rate of the third to that of the fundamental note in a minor key should in strictness be 6 : 5, and in a major key, 5 : 4; and by the compromise just explained, these ratios are obtained with an approach to exactness sufficient for practical purposes.

It is by no means the case that a note of a given name represents, at all times and in all places, the same number of vibrations, or, in other words, has the same absolute *pitch*. This circumstance is sometimes a source of much inconvenience to musicians, for it may happen a piece must be executed with a very different pitch in different cities. It has also been observed that the absolute pitch of the note of given name has shown a tendency to a secular rise. Thus the C, do_4, of Handel is believed to have corresponded with only 499 vibrations; the standard pitch-fork for the same note, authorized by the French Government in 1859, executes 517 vibrations; the tuning-fork sanctioned by the Society of Arts gives 528, in accordance with the recommendation of a congress of musicians at Stuttgard in 1834; what is called *concert pitch* corresponds with 538 vibrations; and the C of the Italian opera is 546.

NOTE B.—FORCE, MOMENTUM, AND WORK.

As additional illustrations, which may serve to fix the ideas of the reader, we give the following brief statements of results, which can be practically verified by experiments with Attwood's machine.

Over a pulley A (Fig. 98), let there pass a perfectly flexible cord, B A C, to each end of which is attached a pile of 32 *half-ounce* weights, so shaped that every one of the 32 can be separately taken from or placed upon either end of the cord, as occasion may require. The *mass* of the wheel and the mass and weight of the cord are supposed to be *nil*, or so small relatively to the weights at the ends of the cord as to be altogether negligible. Friction also and all other resistances are supposed to be abolished. The 32 equal weights at each end of the cord would of course maintain the system in equilibrium if no impressed force act upon it. We now propose this question: What amount of *work* would be required to raise B and depress

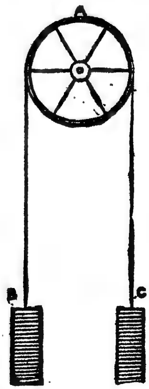


Fig. 98.

C 1 foot? The reader probably knows from other experiences that, with an apparatus constructed as we have supposed, the slightest touch would suffice to set the system in motion, and from the text he will have learnt that this motion will continue with a uniform velocity, which would sooner or later bring the weights into the required positions. The touch might be so slight, that is, the amount of work applied might be so small, that the velocity should be ever so slow; for be it observed that no considerations of time enter into the question. Pushing to the extreme limit, then, the smallness of the pressure required—under the supposed circumstances—the amount of work so required might be said to vanish altogether, for it might be as small as we pleased. But as the weights would necessarily arrive at the assigned position with some velocity, however small, they would possess as moving masses a certain amount of energy, and this energy would in reality be equal to that which had been expended in imparting motion to them. No work would be absorbed by the mere change in the position of the weights. As one descends as far as the other ascends, their common centre of gravity remains at an unchanged level, and no work whatever is done *against the resistance of gravity* in altering the positions of the weights. Thus, when the weights are equal at each end of the cord, the effects of gravity are by compensation practically abolished.

Suppose one of the half-ounce weights removed from B and placed on C; then B will have 31 balanced by 31 on C; but there will now also be on C two unbalanced weights, *i.e.*, equal together to 1 ounce, the downward pressure of which imparts motion to the system—an accelerated motion, as the reader is doubtless aware. If the unbalanced ounce be allowed to act for one second, the system will be found to be at the end of that time moving with a velocity of 1 foot per second. If another weight be removed from B and placed on C, the *pressure* or *force* due to two 1 ounce weights will be applied to producing motion in the *same mass* of metal as before, but the velocity imparted in one second will now be 2 feet. So that when, at the end of the second, the 2 ounces are removed without interfering with the motion, the rest of the system of course continues to move with the velocity it possessed when the impressed force ceased to act, and that velocity will be found to be exactly 2 feet per second. Similarly the transference of each successive half-ounce from B to C will add a foot per second to the acceleration; and when the last weight is removed from B and added to C, the whole will of course then have impressed upon it by gravity, *acting for one second only*, a velocity of 32 feet per second; for it would, in fact, be the case of a body falling freely. It should be carefully observed that in this course of experiments, the *mass* moved would always be the same. Hence, *with the same mass, the acceleration is proportional to the impressed force, i.e., to the acting pressure.*

On repeating such experiments with 17 half-ounces at one end of the cord, and 15 at the other, so that the ounce should again be the acting pressure, it would be found that a velocity of 2 feet would be generated in one second; with 9 half-ounces opposed to 7, a velocity of 4 feet per second would result. In these cases, then, with the same pressure producing motion, the acceleration is *inversely* proportional to the mass. In fact, in whatever way the trials might be varied, the following numerical relations would be found always to exist, provided that the total original mass of the 64 half-ounce weights be called the unit of mass; the downward pressure

of a 1 *ounce* weight, the unit of pressure or force; and the foot per second the unit of velocity:

ACCELERATION = PRESSURE ÷ MASS;

or algebraically,

$$a = \frac{p}{m}$$

It would clearly follow that $a\,m = p$, that is, that the velocity generated in one second multiplied by the mass would equal the pressure. Be it understood, however, that these relations would hold only when the various units are suitably chosen; and in those here employed, it will be observed that the quantity of matter—*e.g.*, brass—in the unit of mass is 32 times that in the unit of weight. With any units, however, it may evidently be affirmed that the velocity produced in a given time by any force acting on a body, is directly proportional to the force, considered as a pressure, and inversely proportional to the mass. Hence also, as $a\,m = p$, the force is directly proportional to the velocity produced in a given time and to the mass jointly; or, in other words, to the *momentum*, since that is the name given to the product of the mass and velocity of a moving body. Hence *momentum is the measure of forces acting on bodies for a given time.* The reader, it may be presumed, has gathered from the text (Chap. XV.) that the *square of the velocity* possessed by a body moving freely under the action of any force (pressure) is proportional jointly to the *force and the distance* through which that force has acted, or, in other words, it is proportional to the *work* done upon the body; hence *the kinetic energy* ($\frac{m\,v^2}{2}$) *is the measure of forces acting on bodies through a given distance.* It is hoped that these hints may aid the reader to distinguish between two modes of regarding force that are sometimes confounded.

We may observe that a portion of the work given out by the descent of the unbalanced weights at one end of the string of the apparatus represented in Fig. 98, is expended in imparting velocity to the acting weight itself, and the remainder in imparting the like velocity to the rest of the moving mass. In the actual machine these velocities may be destroyed at different periods: the velocity of the acting weight, when it is suddenly arrested at any point of the descent; and the velocity of the remaining mass when the descending portion encounters the ground, or a stage on which it impinges. The velocity being thus destroyed, what becomes of the *moving energy*, which represents the work applied to produce the motion? The answer is that it is converted into an equivalent quantity of heat. Does the reader desire an illustration of the transformation of kinetic energy into heat? Let him hie to the nearest blacksmith, and by properly stating his case, he will doubtless be able to induce the local Vulcan to show him how a strong arm, by merely striking a piece of *cold* iron with the hammer on the anvil, can make the iron sufficiently hot to inflame a brimstone match; nay, if he be an expert hammerman, he can even raise the metal to a red heat.

One other remark we have to make. Turning again to the apparatus in Fig. 98, let us suppose that we have, say 1 *ounce* excess of weight on C. When motion is prevented, this ounce will of course press upon the surface beneath it with just the force of an ounce. But when the pressure acts to

produce the uninterrupted motion of the whole mass, the case is different; for a proportion of the action of gravity on the ounce is then employed in producing the motion of the ounce weight itself. In the case supposed, the pressure of the ounce weight on the surface beneath it is, *during the descent*, only $\frac{31}{32}$ of an ounce.

PRINTED BY DALZIEL BROTHERS, CAMDEN PRESS, LONDON, N.W.

Price 3s. 6d. each.

SIR JOHN LUBBOCK'S HUNDRED BOOKS.—*NEW VOLUMES.*

26. **Thackeray's Pendennis.** *5s.*
27. **Thucydides.** *3s. 6d.*
28. **Dickens's David Copperfield.** *3s 6d.*
29. **Byron's Childe Harold.** *2s.*
30. **The Plays of Æschylus.** *2s.*
31. **Smith's Wealth of Nations.** *3s. 6d.*
32. **Chaucer's Canterbury Tales.** *3s. 6d.*
33. **Gibbon's Decline and Fall of the Roman Empire.** 2 Vols. *7s.*
34. **The Dialogues of Plato.** *2s.*
35. **Don Quixote.** *3s. 6d.*
36. **Sheridan's Plays.** *2s.*

ALPHONSE DAUDET'S WRITINGS.—New and Cheaper Editions.

Fancy covers, 2s. each; half bound, 3s. *6d.*

Tartarin on the Alps. With 150 Illustrations. By ROSSI, ARANDA, MYRBACH, MONTENARD and others.

Tartarin of Tarascon. 120 Illustrations.

Thirty Years of Paris and of My Literary Life. 120 Illustrations.

Recollections of a Literary Man. Illustrated by BIELER, MONTEGUT and others.

Artists' Wives. Illustrated by DE BIELER, MYRBACH and ROSSI.

Jack. Translated by LAURA ENSOR, with Illustrations by MYRBACH.

Kings in Exile. Translated by LAURA ENSOR and E. BARLOW. Illustrated by BIELER, CONCONI and MYRBACH.

Robert Helmont. With 123 Illustrations.

(*Uniform with* DAUDET'S *Works.*)

Afloat. By GUY DE MAUPASSANT. With Illustrations by RIOU.

Sister Philomene. By E. and J. DE GONCOURT. Translated by LAURA ENSOR. With 70 Illustrations by BIELER.

ROUTLEDGE'S POPULAR LIBRARY.—*NEW VOLUMES.*

Holdsworth's Family Lawyer.
History of the Bastile.
Foxe's Book of Martyrs.
Roby's Traditions of Lancashire. 2 vols.
Mackay's Extraordinary Popular Delusions.

ROUTLEDGE'S 3s. 6d. JUVENILE BOOKS.—*NEW EDITIONS IN NEW BINDINGS.*

The Young Colonists. By G. A. HENTY.
Every Girl's Book. By LOUISA LAWFORD.
With the Colours. By R. MOUNTENEY-JEPHSON.
Leila; or, The Island. By SARAH TYTLER.
Lilian's Golden Hours. By ELIZA METEYARD.
The Boy's Treasury of Sports and Pastimes.
Helen Mordaunt. By the Author of "Naomi."